ELECTRIC IONS
AND THEIR USE IN MEDICINE

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BY

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WITH

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GEORGIO STOPFORD TAYLOR, M.D.

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TRANSLATOR'S PREFACE

The present seems an opportune moment for presenting this monograph in an English dress. The subject of treatment with ions is one which Professor Leduc has made peculiarly his own. He is a distinguished pioneer in an unexplored country, and in this little book are presented the results of many of his investigations.

I have ventured to add an Appendix in the hope that the methods of treatment described therein will enhance the value of the book for the practical physician.

My cordial thanks are due to my friend Dr. W. C. Oram, who has kindly revised the proofs and afforded me much valuable criticism.

R. W. Mackenna.

Liverpool.

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ELECTRIC IONS AND THEIR USE IN MEDICINE

I. OSMOTIC PRESSURE.

LIVING creatures are made up of solutions separated by walls and membranes which are permeable in different degrees, and between which continual changes are taking place. To know these changes and the actions exercised on them by external influences is to understand life itself. It is the science of life; it is the art of medicine.

* * * * *

A solution is a perfectly homogeneous mixture consisting of a liquid dissolving, or holding in solution, one or more substances called dissolved bodies, which may previously have been in a solid, liquid, or gaseous state. The study of their physical properties led Avogadro to conclude that, under the same conditions of temperature and pressure, equal volumes of different gases always contain the same number of molecules. The molecular weights of different bodies bear the same relation to each other as the weights of equal volumes of these bodies in a gaseous state do under the same conditions of temperature and pressure, and by fixing arbitrarily the molecular weight of one body, all the other molecular weights are determined.

The molecular weight of hydrogen has been fixed at

2 grammes, and the molecular weight in grammes of any body is twice the density of this body in a gaseous state relatively to hydrogen. For shortness, the molecular weight in grammes of any body is designated as a gramme-molecule, or simply as a molecule.

The molecular concentration of a solution is the number of molecules it contains per litre. It is, for any quantity of this solution, the quotient resulting from dividing the number of molecules by the number of litres contained in the given quantity.

A solution with a concentration of a gramme-molecule per litre is a normal solution; that which contains one-tenth of the molecular weight per litre is called decinormal, and so on.

Water freezes at zero centigrade. When one dissolves in water such substances as sugar or alcohol, which, in solution, do not conduct electricity, one lowers the temperature of the freezing-point of the solution proportionally to the molecular concentration. This lowering of the freezing-point is 1·85° for a normal solution—*i.e.*, for a solution containing 1 gramme-molecule per litre. Cryoscopy is the name applied to the estimation of the lowering of the freezing-point of solutions. It enables us to count the number of molecules contained in a litre of any solution. This number of molecules N is equal to the number of times that $\triangle$—the degree of lowering of the freezing-point of this solution—contains 1·85°, which is the lowering of the freezing-point of a normal solution :

$$N = \frac{\triangle}{1{\cdot}85}.$$

M. Van t' Hoff has remarked that, in a solution, the matter dissolved behaves exactly like a gas.

There is a complete analogy between a dissolved substance and a gas. The molecules of the bodies dissolved are mobile relatively to each other, like molecules of gases.

They have, like the molecules of a gas, a tendency to diffuse themselves in a homogeneous manner, so as to fill all the space that the volume of the solvent—which represents the vessel enclosing the gas—affords.

Like the molecules of a gas, the molecules of dissolved bodies exercise, on the limits of the spaces which enclose them, a pressure called osmotic pressure. This osmotic pressure follows exactly the same laws as the pressure of gases, and has exactly the same constants. All the ideas acquired by the study of the pressure of gases are applicable to the osmotic pressures of dissolved substances. As is the case with gases, osmotic pressure is proportional to molecular concentration. For solutions, as for gases, the pressure at 0° for a concentration of 1 gramme-molecule per litre is 22·35 atmospheres.

Cryoscopy, which permits us to count the number of molecules per litre, enables us therefore to measure the osmotic pressure, which is equal to this number of molecules multiplied by 22·35. The freezing-point of blood is $-0{\cdot}56°$. Its molecular concentration is therefore $\frac{0{\cdot}56}{1{\cdot}85} =$ 0·30, a little less than $\frac{1}{3}$ gramme-molecule per litre. Its osmotic pressure is at 0° equal to $0{\cdot}3 \times 22{\cdot}35$, or 6·705 atmospheres.

To get the osmotic pressure at 37°, one must add to this number its product by the coefficient of augmentation of the osmotic pressure with the temperature, which is the same as that of gas—viz., $0{\cdot}00367 \times 37$, or 0·135, which gives 7·60 atmospheres. The pressure of the blood is therefore enormous, being more than $7\frac{1}{2}$ atmospheres. We are compelled to wonder why it does not manifest itself more seriously. This depends on the resistance of the solvent to the movements of the molecules dissolved. A liquid opposes a resistance of 100 square centimetres to the movement of a cube with a side of 10 centimetres. If the same

volume is divided into 1,000 little cubes measuring 1 centimetre per side, the same liquid will oppose to their movement a sectional resistance of 1,000 square centimetres. The resistance of a liquid which opposes the movement of a given mass increases with the division of this mass, and becomes enormous for molecular division. The division of the weight P of any substance in a litre of solution by the number $\left(N=\frac{\Delta}{1{\cdot}85}\right)$ of molecules gives the molecular weight M of the substance dissolved:

$$M=\frac{P\times 1{\cdot}85}{\Delta}.$$

Cryoscopy therefore enables us to determine the molecular weight of substances in solution. Professor Bouchard has employed this method to determine the average weight of molecules eliminated by the urine.

Solutions which conduct the electric current are called electrolytes. They are solutions of salts, of acids, or of bases.

These solutions always have a greater osmotic pressure and a lower freezing-point than one would expect from their molecular concentration. They always behave as if their molecular concentration were higher than that corresponding to the weight of the substance dissolved: as if they contained more molecules than they really do.

This fact has been explained by Swante Arrhenius, who suggests that here again the dissolved substances behave like certain gases—a certain number of their molecules breaking up into fragments, each of the broken-up molecules giving two, three, or four fragments, and each fragment then contributing as an entire molecule to produce the osmotic pressure and lower the freezing-point. If, in consequence of dissociation, the total sum of the active molecules in any solution is three or four times greater than the number of molecules by weight, one must multiply

by two, three, or four the total arrived at, calculated on the molecular concentration in weight, to get the true osmotic pressure and the real lowering of the freezing-point. This coefficient, greater than unity, by which one must multiply the molecular concentration in weight of the electrolytes, is called the coefficient of dissociation, and is often indicated by the symbol i. It represents the proportion in which the number of active molecules in the solution has increased by dissociation.

Osmotic pressure is the force which determines the movements and the rate of exchange between solutions in immediate contact or separated by membranes more or less permeable. Substances in solution move from more concentrated regions towards regions less concentrated, while the fluid moves in the opposite direction. This movement constitutes the phenomenon of diffusion, and osmotic pressure is the motive force which animates matter in this way and produces diffusion.

We have shown by experiment* that diffusion can produce in liquids a structural organization analogous to that of living tissues.

Artificial cells produced by diffusion have a cell membrane, a cytoplasm, and a nucleus, and present, like living cells, a double current of absorption and elimination. By drying the preparation the currents cease, and one has the representation of the latent life of grains and of rotiferæ. One can reproduce all the varieties of cells found in living tissues—polyhedral, elongated and flat cells, as well as cells with ciliary or dendritic processes. One may, by proper nutrition, preserve the activity of artificial cells: they have a metabolism, and extrude certain molecules, while they build up others. They grow by adding cell to cell, giving rise to branching forms and dendritic processes, organizing

* *Comptes rendus de l'Académie des Sciences*; Congrès de l'A.F.A.S., Ajaccio, 1901; Montauban, 1902; Grenoble, 1904; Cherbourg, 1905; and Lyons, 1906.

in their trunks and in their branches a complicated vascular system in which there is a strong circulation.

Some of our artificial granules, consisting of spheres 2 millimetres in diameter, show in a suitable nutritive medium numerous organic outgrowths of 20 to 30 centimetres in length. We know that in the division of cells by mitosis or karyokinesis we see succeed each other in the interior of the cell in a regular order remarkable figures discovered by Hermann Foll, which resemble, although imperfectly, the picture of the fields of electric or magnetic force. There was no force known capable of producing figures in electrolytic solutions similar to those which the cellular cytoplasm produces. We have reproduced by diffusion in electrolytic solutions in their successive regular order the forces, the movements, and the figures of karyokinesis. We have, to begin with, reproduced the achromatic figure.* We have then showed that one can reproduce by diffusion all the phenomena of division of the nucleus.†

In our experiments our artificial nuclei, formed at first of chromatic granules, gave place to the formation of a rolled-up ribbon, a spirema with sacculations. This ribbon became smooth, with a double contour. It divided into chromatic bands, which arranged themselves in the equatorial plane, and then in the vertical plane. These chromatic bands then straightened out and travelled from all directions towards two centres of attraction, remaining united only by fine filaments, vestiges of the primitive nuclear spindle. The evolution ended by the production

* *Comptes rendus de l'Académie des Sciences;* Congrès de l'A.F.A.S., Ajaccio, 1901; Montauban, 1902; Grenoble, 1904; Cherbourg, 1905; Lyons, 1906.

† *Comptes rendus de l'Académie des Sciences*, 1904; *Revue scientifique*, 1906; Congrès de l'A.F.A.S., Grenoble, 1904; *Versammlung Deutscher Naturforscher und Aerzte*, Meran, 1905; *Physikalische Zeitschrift*, 1905; Congrès de l'A.F.A.S., Lyons, 1906.

of two artificial cells which had the centres of attraction for nuclei. These centres of attraction, formed simply by two centres of osmotic pressure, behave exactly like the centrosomes introduced into the ovule by the spermatozoon. At the Congress of the French Association for the Advancement of Science we showed how very gradual movements of diffusion, such as those produced in the egg by incubation, resulted in a segmentation of liquids very analogous to that of the vitellus.*

* * * * *

Of late years numerous researches have been published with a view to establish a line of demarcation beween crystallizable substances or crystalloids, and solutions of non-crystallizable substances or colloids.

The latter, it is said, do not diffuse, have no osmotic pressure, and do not lower the freezing-point; while they diffuse light, and form with water suspensions, and not solutions, etc. This view, which has found a particular vogue in Paris, seems to me regrettable from the point of view of biology and medicine. There is no sharp limit between the solutions of crystalloids and colloids. For, as all the properties of the one are found in the other, the transition is insensible, and there exist only differences in degree.

As colloids have very large molecules, their solutions always have a feeble molecular concentration and feeble osmotic pressure. But just as it is under extremely feeble pressures—pressures of a millionth part of an atmosphere—that gases exhibit their most curious and important properties—that they, for example, give us cathode and 'X rays'—so the feeble osmotic pressure of the colloids of the organism, albuminoids of every kind, has the greatest significance for biology. The persistent tendency to deny this osmotic pressure turns one away from its study, while

* Congrès de l'A.F.A.S., Cherbourg, 1905; *Versammlung Deutscher Naturforscher und Aerzte*, Meran, 1905.

works devoted to separating the colloids from crystalloids tend rather to retard than to advance biology and medicine.

We observe in living creatures numerous movements of orientation or change of position called tropisms or tactisms. We have demonstrated that, in a liquid, all points having an osmotic pressure greater than that of the liquid—hypertonic points—or all the points having an osmotic pressure less strong—hypotonic points—are centres of force, and we have called these points positive and negative poles of diffusion.* We have shown that between these poles the same dynamic action is exercised, and follows the same laws, as between magnetic poles of the same or the opposite name. These forces produce kinetic actions, movements which seem to represent those designated by the biologists under the name of tropisms and tactisms, which are nothing more than direct or indirect cases of what we have called osmotropism and osmotactism. As Oscar Hertwig says, in his 'Cellular Physiology,' à propos of chemiotaxis, 'The phenomenon depends not only on the chemical nature of the substance, but also on its concentration, and is negative or positive according as the concentration is feeble or strong.'

Agglutination would also seem to be explained by osmosis. All the cells of the organism are extremely sensitive to the influence of differences in osmotic pressure. In concentrated solutions of chloride of sodium the blood-corpuscles give up their water, contract and break up. In water, and very dilute solutions of sodium chloride, the fluid which penetrates into their interior swells them up, makes them burst, destroys them, and dissolves out their hæmoglobin (Hamburger). Epithelial and nerve cells are not less sensitive to differences of osmotic pressure. We have had occasion to observe a certain number of cases of rhinitis and of very severe anosmia following on the introduction

* 'Champs de force de diffusion,' Congrès de l'A.F.A.S., Montauban, 1902.

into the nasal fossæ of too concentrated salt solutions. Pure water is very caustic. At Gastein in the Tyrol there is a spring called Giftbrunnen, which means 'a poison spring.' The water of this spring is the purest known; and for this reason it causes the epithelial cells of the digestive tube to swell and be destroyed, and produces the harmful effects which have earned for it this name. Drinking-water is never pure, for it contains in solution salts taken up by the soil, and gases taken from the atmosphere, and it has therefore a marked osmotic pressure which robs it of its power of doing damage by osmosis. Whenever one makes a wound one should take into consideration the osmotic pressure of the liquids brought into contact with it, in order to avoid damaging the vitality of the living surfaces. This precaution is still more necessary when foreign liquids are put in contact with the delicate cells of surfaces covered with serous membranes. Gardeners have recognized this influence of osmotic pressure, and consequently they make water-trenches in the soil at the base of their plants, as water poured on the heart of the plants, having a too feeble osmotic pressure, makes the cells burst and destroys the plant. Moist applications to remove dry crusts, such as those of eczema and impetigo, are more successful the lower the osmotic pressure of the liquid employed. The most useful applications for this purpose are compresses of absorbent lint impregnated with boiled distilled water, under the influence of which the morbid cells rapidly swell up, burst, and are dissolved.

* * * * *

To recapitulate: the comparison of dissolved substances with gases has brought to our knowledge a force of which we were previously but dimly conscious. It has enabled us to understand the laws of this force—laws which were laboriously discovered by the study of gases. We find this force in play in all the phenomena of life. It is present everywhere, and where it ceases to exist life is extinguished.

In plants, as in animals, the conservation of life requires the continual maintenance of differences of molecular concentration between the different parts of the body, and from this results the osmotic pressure necessary to animate the matter. For plants, the rain keeps up the humidity of the soil; the sun and the wind acting on the surface of the leaves concentrate the juices of the sap. In man and animals the ingestion of fluids tends to lower the molecular concentration, while, on the other hand, pulmonary and cutaneous evaporation increase it. We have shown* that osmotic pressure in the molecules is raised by muscular contraction, and rises more the greater the amount of work done by the contraction. If most of the effects of osmotic pressure still elude our observation by reason of their complexity, it is because of the imperfection of the means at our disposal to study them and watch their results. Scientific method prescribes for us the necessity of determining completely the actions of osmotic pressure in all the phenomena of life where we find this force in play. Even if we cannot do this, to invoke a hypothetical force is but to return to ancient animism, to forsake scientific method, and to repudiate all modern science. By the examples which we have given one can see how the knowledge of osmotic pressure and of its laws finds its application in the facts of everyday medical practice, and can appreciate how much it contributes to the perfection of the physician in helping him to understand the phenomena in presence of which he finds himself, and on which he has to exert his influence. This knowledge is necessary to guide his therapeutic interventions, to keep him from doing harm, and to increase his power to heal.

* *Comptes rendus de l'Académie des Sciences*, May, 1905.

II. THE IONS.

Salts are now regarded as formed by the union of a metal, M, or a metallic radical with an acid radical, R. In sulphate of potash, for example (K_2SO_4), the metal is K_2, the radical SO_4. Acids may be regarded as salts whose metal is hydrogen. Sulphuric acid (H_2SO_4) is therefore a sulphate of hydrogen. Bases may be regarded as salts whose acid is hydroxyl (OH)—*e.g.*, potassium hydrate (KOH). We may therefore represent—

Salts by the symbol	R.M.
Acids by the symbol	R.H.
Bases by the symbol	OH.M.

This constitution has been revealed by the action of the electric current on solutions of salts, acids, and bases. Solutions which conduct electric currents are called electrolytes. The conductor in connexion with the positive pole of the generator, and by which the current arrives at the electrolyte, is called the anode. The conductor by which the current leaves the electrolyte is called the kathode. When a current is made to pass in an electrolyte, the acid radicals and the hydroxyl (OH) are always set free in the region round the anode. They therefore move in the electrolyte from the kathode to the anode, and thus they travel against the current. The metals, which include hydrogen, and the metallic radicals become free at the kathode, and move in the electrolyte from the anode towards the kathode: they travel with the current. Faraday gave the name of ‘ ions ’ (*i.e.*, travellers) to those constituents of the electrolyte which are set free at the electrodes under the influence of the electric current. He called those which are freed round the anode anions, and those which are freed round the kathode kations.

While solutions of substances which do not conduct electricity, such as sugar, alcohol, etc., always have an osmotic

pressure and a lowering of the freezing-point exactly proportional to the molecular weight of the dissolved substances, all electrolytic solutions have an osmotic pressure and a lowering of freezing-point greater than that calculated according to the molecular weight of the substances dissolved. Electrolytic solutions behave as if they contained more molecules than they do. Swante Arrhenius has explained this anomaly by taking for granted that some of the molecules break up by dissolution into fragments which participate like whole molecules in producing the osmotic pressure and in lowering the freezing-point. The fragments resulting from the dissociation of molecules are the ions, and these ions are the carriers of electric charges, to which the electrolytic conductivity is due. The anions carry negative charges, and are consequently attracted by the positive electricity of the anode. The kations carry positive charges: they are repelled by the anode and attracted by the negative electricity of the kathode. On coming in contact with the electrode, the ions are unloaded, neutralizing quantities of electricity equal to, and of opposite sign to themselves; and these quantities of electricity will be replaced by new charges coming from the generator, and it is thus that the electric current is produced and maintained. Plurivalent ions carry electric charges proportional to their valency; or, rather, it is the electric charges which determine the valency. For this reason the ion $SO^{4=}$ is bivalent in solutions of sulphate of potash, $SO^{4=}K^+K^+$ and the iron ion trivalent in solutions of perchloride of iron, $Fe+++Cl-Cl-Cl-$.

In consequence of this dissociation, an electrolytic solution contains three kinds of particles: neutral molecules, anions, and kations. A solution of chloride of sodium, for example, contains neutral molecules of NaCl, chlorine anions carrying negative charges which are represented by the symbol $Cl-$, and kations of sodium carrying a positive charge, and represented by the symbol Na^+. If we

represent the total number of molecules in the solution by N, and the number of molecules dissociated by N^1, the relation $\frac{N^1}{N} = d$ represents the degree of dissociation. With a certain dilution all the molecules are broken up—$N^1 = N$, and $d =$ unity. One must not confuse the degree of dissociation, which is always smaller than unity, with the coefficient of dissociation, which is always greater than one. The latter is the ratio between the total number of complete neutral molecules and ions taking part in the production of the osmotic pressure and the number of molecules dissolved. My distinguished friend, Dr. Lewis Jones of London, has given in the *Lancet* a very striking picture of an electrolytic solution, which he compares to a ballroom containing dancers united in couples who represent the neutral molecules, and a certain number of isolated ladies and gentlemen who represent the dissociated ions. If at one end of the room there is a large mirror, and at the other a buffet supplied with champagne and good cigars, and the ladies make their way to the mirror while the men go to the buffet, and the dancing partners separate to follow the movement, the room presents the picture of an electrolytic solution at the moment when the current is passing.

If we divide an electrolytic cell into two by a porous partition, we find, after the decomposition of one or several equivalents, an unequal redivision of the loss. In the case of sulphate of copper, for instance, the negative tub or cell has undergone a loss of two-thirds of its concentration, and the positive vessel only one-third. In 1853 Hittorf gave the following ingenious explanation of this phenomenon:

$\overset{=}{SO^4}$	$\overset{=}{SO^4}$	$\overset{=}{SO^4}$	$\overset{=}{SO^4}$	$\overset{=}{SO^4}$	$\overset{=}{SO^4}$
$\overset{++}{Cu}$	$\overset{++}{Cu}$	$\overset{++}{Cu}$	$\overset{++}{Cu}$	$\overset{++}{Cu}$	$\overset{++}{Cu}$

FIG. 1.—BEFORE THE PASSAGE OF THE CURRENT.

Fig. 1 represents an electrolytic cell containing sulphate of copper; the vertical line represents the porous partition separating this cell into two equal parts.

$$-\left|\begin{array}{cccc:ccccc} & & & SO^{\overline{\overline{4}}} & SO^{\overline{\overline{4}}} & SO^{\overline{\overline{4}}} & SO^{\overline{\overline{4}}} & SO^{4} & SO^{4} \\ Cu & Cu & Cu & \overset{++}{Cu} & \overset{++}{Cu} & \overset{++}{Cu} & & & \end{array}\right|+$$

FIG. 2.—AFTER THE CURRENT PASSES.

Fig. 2 shows the state of the cell after the passage of the current, allowing that the acid radical is displaced twice as quickly as the kation—that is to say, that two acid radicals pass through the partition to go towards the anode, while only one copper ion traverses it towards the kathode. We see that three ions are liberated at each electrode, but in consequence of the difference in the speed of the ions, the negative half of the cell does not contain more than one molecule of sulphate of copper, having lost two-thirds of its concentration, while the positive half contains two parts, having lost only one-third of its concentration. It is easy to conclude from this that the ions move in opposite directions at different rates, and we see that the loss of concentration (n) at the kathode and ($1 - n$) at the anode are related to one another in the ratio of u, the speed of the anions, to v, that of the kations:

$$\frac{n}{1-n} = \frac{u}{v},$$

and we have in the losses of concentration the means of determining the relative speeds of the ions. In 1876 Kohlrausch, in comparing, under identical conditions, the conductivities of salts formed from three or four anions united successively with several kations—for example:

$$\begin{array}{c} Cl—K—Na—NH^4, \\ Br—K—Na—NH^4, \\ I—K—Na—NH^4 \end{array}$$

(the conductivity of the chlorides, bromides, and iodides of potassium, sodium, and ammonium, etc.)—found between the different salts of one and the same kation the same differences of conductivity, which consequently depend entirely on the differences of the anions, and show themselves independent of the kation with which the anions are united. Similarly, the analogous experiments made with three or four kations united successively to different anions show conductivities differing in the salts formed from one and the same anion but varying kations, and these differences are always identical for the same kations, and are consequently independent of the anion with which they are united. The law of Kohlrausch is expressed in the formula $C = d(u + v)$, in which C is the conductivity of the salt, d the fraction of the electrolyte broken up into ions (degree of dissociation), u and v the velocities of the anions and the kations respectively.

When all the electrolyte is broken up, $d = 1$, and the formula becomes $C\infty = u + v$.

The specific conductivity of an electrolyte—*i.e.*, the conductivity (the inverse of the resistance $C = \frac{1}{R}$) in ohms of one centimetre cube of this electrolyte—is represented by y. Molecular conductivity is represented by Cm, and is that of an electrolyte containing one molecule, and placed between two parallel electrodes 1 centimetre distant from each other. The thickness of the fluid layer being 1 centimetre, the volume is equal to the section in square centimetres, and the molecular conductivity to the product of the specific conductivity by the molecular volume. The molecular conductivity varies with the dilution, and consequently with the molecular volume. Molecular conductivity reaches its maximum when dissociation is complete. It is then represented by the symbol $C\,\infty$.

To recapitulate, electrolytic conductivity is proportional to the number of ions, to their velocities and their charges.

* * * * *

The chemical actions, and consequently the toxic, antiseptic, and remedial actions, of electrolytic substances are almost exclusively the actions of their ions. For instance, a solution of nitrate of silver is precipitated by chlorine with the production of chloride of silver, but only in solutions like those of chloride of sodium or of potassium, in which the chlorine is in the state of the chlorine ion $Cl -$. In solutions of chlorate of potash and chloracetic acid, where the chlorine ion is part of more complex ions ($ClO_3 -, C_2CH_3lO_2 -$) a solution of nitrate of silver does not produce a precipitate. Toxic and pharmacological properties depend essentially on the grouping of ions: it is neither the atom nor the molecule, but the ionic grouping, which it is important for the physician to recognize. Take, for instance, the phosphides and the phosphates. Some are very toxic, while others have no toxicity. No analogy exists between their action on living beings. If they are united with kations of indifferent or feeble action, all the phosphides produce the same toxic or therapeutic effects. The same is true of the phosphates. It is to the phosphorus ion that the phosphides owe their toxic or therapeutic properties. The molecule of the phosphates contains phosphorus in the same proportion as the phosphide molecule, but this phosphorus is part of a complex ion ($PO_4\equiv$) whose properties are quite different from those of the phosphorus ion of the phosphides. These remarks apply also to the sulphates and the sulphides, and in general to all the ions. The cacodylates and the arsenates have been extolled extravagantly as arsenical preparations to be used instead of the old preparations. There is, however, no analogy between the medicinal and toxic actions of these and the arsenides and the arsenites. In them the arsenic ion is part of a complex anion, and does not preserve any of its characteristic properties. One does not think of beginning a course of iron treatment with the ferro- or ferricyanides. They contain iron, but they do not manifest any of the properties of the iron kation, but very

markedly those of the complex anion, of which the iron is a part.

Certain solvents, much used in medicine, such as alcohol, chloroform, glycerine, and vaseline, do not dissociate the electrolytes, and consequently the latter do not exhibit their usual chemical properties when mixed with these solvents. These solutions do not conduct electricity. This absence of dissociation in certain solvents explains, by the suppression of their ionic effects, the disappearance in certain preparations of the medicinal, toxic, and caustic properties of the substances. Phenol in pure glycerine is almost non-caustic, and only slightly toxic. We have known several persons who have taken as much as a tablespoonful of equal parts of phenol and glycerine without either being burned or poisoned. The same dose diluted with water would have been fatal. An ointment containing vaseline or glycerine and 5 per cent. of phenol will make an excellent dressing for an ulcer of the leg, and will not produce the slightest caustic or irritant effect, while a 5 per cent. aqueous solution of phenol applied as a permanent dressing will produce a most serious result. The same holds true of all electrolytic substances, and there is room to hope that medicine will derive much benefit from the light which the theory of ions throws on this matter.

Since chemical, toxic, and medicinal actions are the actions of ions, they should be proportional to the ionic concentration—*i.e.*, to the number of ions in a given volume. These actions depend directly on the degree of dissociation. The degree of dissociation of any electrolyte is the coefficient of its chemical and its medicinal activity. For example, all acids have the same kation, the ion hydrogen. They have all identical properties, but their actions differ according to their intensities. There are strong acids like sulphuric acid, and feeble acids like acetic acid. Strong acids are acids very much dissociated, and in their solution the hydrogen ion is very much Con-

centrated. Feeble acids are very little dissociated, and their solutions contain the hydrogen ion in a very dilute form. This idea of the ionic nature of medicinal action and of its intimate relation to the degree of dissociation should be more recognized in medicine. If, for example, we wish, when dealing with an infected focus, such as a purulent otitis or arthritis, to use an antiseptic like phenol or a salt of zinc, etc., in strong concentration, we should choose a solvent like glycerine or the oils which have only a slight degree of dissociation, and we should carefully refrain from all washing with water before or after the application. The dissociation necessary for the remedial action then takes place slowly and regularly in contact with the organic fluids, and, so to speak, as free ions are required. It is for this reason that surgeons have been able to inject equal parts of phenol and glycerine into purulent foci, but as they did not know the physical properties which rendered this practice possible, they ignored the importance of avoiding washing with water.

In 1896 and 1897 Paul and Krönig showed that the bactericidal action of salts varies with their degree of dissociation, just as the activity of acids does, and is therefore attributable to the concentration of the active ions. For example, they studied the action of bichloride, bibromide, and bicyanide of mercury on the spores of *Bacillus anthracis*, and found 7 colonies after a solution containing one molecule of $HgCl_2$ in 64 litres of water had acted for twenty minutes. After the action for the same length of time of a similar solution of $HgBr_2$, the number of colonies was 34. The bibromide, therefore, exercises an antiseptic action nearly five times less than the bichloride. But a solution of bicyanide of mercury ($HgCy_2$) four times more concentrated—*i.e.*, with one molecule in 16 litres of water—allowed, after acting for twenty minutes, the development of an incalculable number of colonies. This solution had, therefore, not exercised any appreciable

antiseptic action. After acting for eighty-five minutes, the solutions of $HgCl_2$ and $HgBr_2$ did not allow any colonies to develop; but the more concentrated solution of $HgCy_2$ still allowed 33 colonies to develop. In all these solutions the proportion of Hg is the same, and the ion Cy ought to be more active than Cl – and Br –. The physical quality in these solutions, which varies in proportion to their activity, is the degree of dissociation. In reality, the active ion is the ion Hg^{++}, which is very concentrated in the solution of $HgCl_2$, which is markedly dissociated, less concentrated in the less dissociated solution $HgBr_2$ and finally very diluted in the very slightly dissociated solution of $HgCy_2$. What we learn from experiments as to the bactericidal action of solutions of mercurial salts, observation enables us to recognize for their therapeutic actions, and we may be seriously misled if we judge of the medicinal activity of a solution of a salt of mercury, or of an electrolytic solution in general, by its concentration in weight, or even its molecular concentration, without taking into account the degree of dissociation which is the true coefficient of activity. At the Congress of the Association for the Advancement of Science held at Paris in 1900 we concluded a communication on the treatment of tabes by intramuscular injections of sublimate of mercury with the following summary:

Preparations of mercury or potassium iodide taken by the mouth have no action, or, at most, a feeble one, on locomotor ataxia. Corrosive sublimate injected intramuscularly, on the other hand, always exercises a beneficent effect. If the ataxia is recognized and treated by intramuscular injections of sublimate as soon as the first symptoms appear, the disease will be completely recovered from. When ataxia is already advanced, intramuscular injections of sublimate diminish some of the symptoms and arrest the progress of the disease. It is more especially those cases of syphilis treated insufficiently in the beginning, slight cases

which may not have been recognized, or have been neglected, which produce locomotor ataxia. At that time these conclusions were heterodox. It was taught that tabes was a parasyphilitic affection, and that specific treatment never cured but always aggravated it. In spite of the high and legitimate authority of the masters who held and still hold this view, most physicians have recognized the authority of facts, and apply specific treatment to tabes.

Two conditions are indispensable for success: (1) One must begin treatment early before the nerve elements are destroyed by fibrous proliferation; (2) one must know how to avoid useless treatment, and practise an efficient therapy. It is on this point that the theory of ions gives us light. In therapeutics we employ indifferently all the salts which contain mercury—the salts of organic acids, which are not dissociated at all, and others in which the Hg, being a part of complex ions, has lost all its properties. The principal reasons for the choice of these preparations is that they do not cause pain; but, like the bactericidal action and the therapeutic action, pain seems to be produced by the iron Hg^{++}, which is the active ion, and in the methods used one only avoids pain at the sacrifice of efficiency. With these inactive preparations it is not surprising that their efficiency should be denied. The addition of chloride of sodium to solutions of sublimate lessens their coagulating action on myosine, as well as the pain they produce: this result is due to the fact that chloride of sodium retards the dissociation and diminishes the concentration of the ions Hg^{++}; but by diffusion in the blood, and through the regulating action of the economy on the concentration of NaCl, the dissociation returns to what it would have been without the addition of chloride of sodium. A more efficacious means of diminishing the pain produced by intramuscular injections of sublimate consists in not allowing the ion $Hg++$ to act at the point of injection

except under feeble concentration. This may be effected by injecting weak solutions slowly. Water by itself does not produce any irritation. Instead of employing, as is often done, solutions of dilutions (1 in 100), we inject gradually five times as great a volume of a solution of 1 in 500, or ten times as great a volume of a solution of 1 in 1,000. In this way one will not produce either pain or induration by injecting into the muscles of the buttock, in the space of two minutes, 5 to 10 c.c. of the following solution:

Sublimate	20 centigrammes.
Chloride of sodium, recrystallized	1 gramme.
Distilled water	100 grammes.

The injection is practised twice weekly. In this way one can regulate with precision, according to the effects, the dose and absorption of an active and efficient remedy. These examples show that it is not only in electrolytic medication that the theory of ions is useful for the physician, but in pharmacology and general medicine as well.

III. GENERAL THEORY OF ELECTRICITY.

A convenient manner of representing electricity is to compare it to a current of water. Every electrical installation may be represented by a combined suction and force pump, an indiarubber bulb which sucks up the water from a lower reservoir, and raises it to a higher reservoir, from which it falls through a spout into the lower vessel, setting in motion in its course some form of turbine. The pump or the bulb is the generator of hydraulic energy, and corresponds to the generator of electric energy. The turbine is the receiver, and represents the apparatus through which the current of electricity is made to pass to produce the

effect desired. In medicine the receiver is thc subject traversed by the current in which a part of the electrical energy is absorbed and transformed. The rcservoirs represent the poles of the generator; the tubes and taps the conductors of the electric currents. The motive-force which drives the pump or bulb is analogous to what is called in electricity the electro-motive force. The difference of the level of the liquids in the two reservoirs is what is called in electricity difference of potential. The outflow—*i.e.*, the quantity of water which pours out in a unit of time—represents what one calls in electricity the strength of the current, while the obstacles, such as friction, etc., which are opposed to the current are called in electricity the resistance of the conductors.

The resistance of a conductor depends on its nature. It is directly proportional to its length and inversely proportional to its cross-section. The larger the tubc, the less resistance it offers to the current which passes through it. The outflow of a current of water is greater the greater the force driving the pump which propels it, and the less the resistance opposed to the current. The intensity of an electric current is greater the greater the electro-motive force and the less the resistance of the conductor. This is Ohm's law, the formula for which is $I = \frac{E}{R}$. (Intensity or strength of current is equal to the electro-motive force divided by the resistance.)

Motive-force is expressed in kilogrammes; electro-motive force is expressed in volts. The volt is the electro-motive force of a certain standard generator chosen as unity. The resistance of an electric conductor is expressed in ohms; the ohm is the resistance of a certain standard conductor chosen as unity. The strength of an electric current is expressed in ampères, and the unit of current, the ampère, is the current which an electro-motive force of 1 volt produces in a circuit whose resistance is 1 ohm. The unit

of current employed in medicine is the one-thousandth part of an ampère, or the milliampère. The unit of quantity of current is the coulomb; it is the quantity of electricity delivered by a current of 1 ampère in one second. One other point of great importance in medicine is the density—*i.e.*, the quotient $\frac{I}{S}$—of the intensity of the current by the surface of the conductor. In other words, the density is the intensity of the current which traverses each unit of area of the section of a conductor. We know that if we introduce into a patient a current of 100 milliampères by a surface of 1 square centimetre we will have effects very different from those produced by the same current of 100 milliampères entering a surface of 100 square centimetres, each square centimetre being traversed only by 1 milliampère in place of a hundred.

The density should therefore always be carefully considered in the application of electric currents in medicine. A current in medicine cannot be estimated by its intensity alone without considering the surface of its application. Electric conductors, in consequence of their resistance, always absorb a certain proportion of electrical energy, which is transformed into heat according to the laws of Joule—that is to say, proportionally to the product of the electro-motive force by the intensity and the time; or, by replacing the electro-motive force by its value I.R. derived from Ohm's law, the quantity of energy changed into heat in a conductor is proportional to the square of the intensity multiplied by the resistance and by the time. When a conductor, traversed by an electric current, is in the neighbourhood of a magnetic needle, they tend to cross each other—to place themselves perpendicularly to one another. If it is the needle which is mobile, the needle moves; if, on the contrary, the magnetic needle is fixed, and the conductor is mobile, it is the conductor which moves. The force thus exerted between magnets and conductors tra-

versed by currents is proportional to the intensities of these currents, and serves for measuring the intensities. The apparatus actually used is made of a fixed magnet, in the form of a large open ring, in whose opening, crossed by the magnetic field of the ring, is a small mobile conductor composed of several coils of wire, which, under the influence of the magnet, tends to move from 90 degrees when it is traversed by a current. A fine watch-spring opposes this movement. The axis of the mobile conductor carries a light needle which moves on a dial graduated in milliampères, and the instrument is called a milliampèremeter. By a simple reading one can tell the intensity of the current which traverses it, and as the needle fixes itself without oscillating at each of the positions which it ought to occupy, it is called the aperiodic milliampèremeter. This valuable instrument is due to the ingenuity of Professor d'Arsonval.

We have seen that electro-motive force is proportional to current, and we can therefore measure it with the same instrument, which for this purpose is graduated in volts, and called a voltmeter. The current whose intensity we wish to measure should all pass through the ampèremeter. If, however, one wishes to measure the difference of potential between the entrance and the exit of the current in any subject, one must place the voltmeter in a branch circuit between these two points. Hence the ampèremeter should have as low an internal resistance as possible, so that very little of the electric energy may be absorbed; but the resistance of the voltmeter should be as great as possible, so that it may alter by a minimum the flow of the current.

The sources of continuous currents used for medical applications are galvanic cells, accumulators, and the city mains, which latter give a continuous current with a difference of potential of 110 volts or 220 volts. Batteries are made up of a certain number of elements. Each element

consists of an electrolytic solution—acid, salt, or base—contained in a vessel in which are immersed two conducting plates, whose projecting extremities are the poles of the element. One of the plates is a metal which is acted upon by the liquid, and constitutes the negative pole. The other is a conductor which is not acted upon—*e.g.*, carbon, copper in a solution of copper, etc.—and constitutes the positive pole. As soon as the circuit is closed—that is to say, when the positive and negative poles are connected—a current is set up, and the sensitive metal is dissolved in the electrolyte, and sends from it kations which go to replace those of the electrolyte which are set free round the positive pole. These kations will be positively charged, and as a positive charge never appears without an equivalent negative charge, the plate forming the negative pole, usually of zinc, becomes negatively charged. To recapitulate, it is at the point of contact of the zinc and the electrolytic fluid that the electro-motive force originates, in consequence of which the zinc becomes negatively charged, though the zinc ions which pass from it into the fluid take with them a positive charge, which they communicate to the liquid and to the insensitive plates which constitute the positive pole. When the electrolyte is composed solely of an acid solution, the hydrogen ion, displaced by the zinc ion, disengages itself round the positive pole, and forms a very resisting gaseous sheath, and tends, on the other hand, to produce an inverse electro-motive force, and thus weakens the force of the current, conforming to the general law of Nature that every action provokes a reaction. Its resistance diminishes the electro-motive force of the element, and constitutes polarization. Such is the general physiology of the electric cell. All its varieties have as their aim the discovery of liquids which, acting upon zinc, give the greatest electro-motive force, and which best avoid polarization by hydrogen. Like every conductor traversed by a current, cells have an internal resistance which, as we have seen, is

weaker the greater the section of the conductor—*i.e.*, the larger the cell.

Nowadays, when we employ in medicine much stronger currents than formerly, the cells should have as small a resistance as possible, and therefore be of some size. With small cells, having a great internal resistance, one cannot efficiently apply treatment with ions.

Accumulators are reversible cells which have to be regenerated—*i.e.*, recharged by an electric current which produces a chemical action the inverse of that which produces the E.M.F. The elements of the battery used in medicine have an E.M.F. of about 1·5 volts. To apply treatment with ions, one requires about 40 to 50 volts, which, with a total resistance of 400 to 500 ohms, will give a current of 100 milliampères.

$$I = \frac{E}{R} = \frac{50}{500} = 0{\cdot}100.$$

Thirty cells of a volt and a half suitably connected will give 45 volts. For this purpose one must connect the elements in series—*i.e.*, the positive pole of one cell to the negative pole of the next. In this way the E.M.F. is increased, as is also the resistance; but one must choose cells with as small an internal resistance as possible. Manufacturers sell elements already set up, but the physician ought to know how to choose for himself an apparatus suited to the conditions he wishes to fulfil. If he trusts to the manufacturer for his choice, he will probably fail to realize his aims.

In the application of the electro-ionic method, the E.M.F. should be introduced very gradually. No one can tolerate the sudden introduction or suppression of an E.M.F., which he will bear perfectly if it is gradually introduced or removed. There are two methods of graduating at will the E.M.F. and the current. One consists in introducing into the circuit a variable resistance called a rheostat. With a

strong resistance one can at the outset throw the whole E.M.F. into the circuit; the difference of potential between the entrance and the exit of the current in a patient is feeble, and by progressively lowering the resistance of the rheostat one gradually elevates the difference of potential applied to the patient and the strength of the current which passes through him.

Another mode of graduating the current, more generally employed, and perfectly efficient, consists in employing a collector. One of the conductors being fixed to one of the terminals of the cell, the other is placed successively in communication with each of the succeeding elements; but in order that the circuit may not be broken at any point, and to avoid all sudden shocks, the communication with the next element is made before that with the preceding one is broken. This result is obtained by contacts, usually arranged in a dial on the lid of the box which holds the cells; each contact is in communication with one of the conductors, uniting the elements between them, and on these contacts there moves like a needle a broad 'hand,' which never leaves one contact before touching the next. All the surfaces of the friction contacts which are in apposition should be kept scrupulously clean, free from rust or dust, which may interrupt the current, and produce shocks which the patient cannot bear, and which interfere with the treatment.

Accumulators are used in the same way as batteries.

To use the continuous current from the city mains one employs instruments called reducers of potential. They are secondary circuits of a high resistance, in passing through which the potential gradually changes. One of the conductors is fixed to one of the terminals; the other is moved from contact to contact, and as the distance between them increases the difference of potential between them is raised.

A reducer of potential for 110 volts can be used for

220 volts by putting in series a 110 volt incandescent lamp.

To connect patients with the generators we employ electric conductors, called rheophores, or simply cords. These ought to be 1·50 metres long; they should be pliable, and must be securely fixed to the terminals and covered with a sheath of insulating material to protect them from fluids and oxidation. At the generator end they terminate in a metal peg, which should be fixed to the generator so as to insure perfect contact, but one should not accept conductors terminating at the other extremity in a metallic peg like those always supplied by the manufacturers. The cord should be fixed with a solid solder joint to a sheet of very pliable tin, so that it may be adapted to the curves of the body—*e.g.*, rolled round a limb, such as the thigh or the thumb. One should have a number of plates of different dimensions securely soldered to their rheophores, some to circle the thumb, others to cover the whole half of the thorax. The customary method of uniting the conductor to the plate by a peg is defective and dangerous. If the peg is pulled out or even shaken by some movement or other the patient may receive a very painful shock, and the treatment be brought into disrepute.

For treatment with ions requiring strong currents, such an accident should be rendered impossible. The conductors in immediate contact with the patient, and by which the ions are introduced, are called electrodes. The following accident will explain why one should entirely reject all the varieties of electrodes hitherto supplied by the maker and employed by the physician.

In a class experiment I introduced rapidly—*i.e.*, with a strong current—an innocuous ion into the body of a rabbit. The animal was suddenly seized by severe tetanic spasms and died. The electrolytic solution used for the introduction of the ion impregnated a thick pad of absorbent cotton, but the laboratory assistant had placed on this

absorbent cotton an ordinary electrode of commerce (a metal plate covered with chamois leather), which some days previously had been soaked in a solution of strychnine, which the assistant believed he had removed by washing with water.

For electrodes we employ a tissue of absorbent lint. To avoid the ions proceeding from or being produced at the point of contact of the metal plates, we fold the tissue in eight or sixteen thicknesses. It absorbs the solution to be used well, and affords a perfect contact with the skin. It is covered with a pliable metal plate to which the conductor is soldered, and the whole is firmly fixed with a bandage of the same absorbent cotton tissue. After each séance the tissue is carefully washed, and the method insures a precision of technique which the electrodes in use to-day fail to do. The concentration of the solutions which impregnate the electrodes has no influence on the introduction of the ions. The effects produced depend only on the nature of the ions and on the rapidity of their introduction—*i.e.*, on the strength of the current. In other respects, however, the concentration is not negligible. We know that if we apply to the skin 1 per cent. solutions of strong acids or bases we will produce direct caustic actions without any electric current. If we desire to introduce gradually the hydrogen (positive) or hydroxyl (negative) ions of these solutions, we must employ dilutions of at least 1 per 1,000. The only advantage of using strong concentrations is to diminish the resistance of the electrodes, and to protect oneself from the action of foreign ions proceeding from the metal plates. When we employ a neutral salt with a small degree of dissociation, which has no direct action on the skin, we should employ a solution of from 1 to 5 per cent.

But the active electrolytes, like the acids and the bases, are only active, as we have already seen, because they have a high degree of dissociation, because they contain a large

number of ions, and in great dilution are very good conductors, and afford a satisfactory protection against foreign ions.

IV. ELECTROLYSIS OF LIVING TISSUES.

Up till now in medicine the word 'electrolysis' has been reserved for those applications of the electric current which produce caustic effects. This restriction is unreasonable. A more exact knowledge of phenomena shows that all the effects produced by the electric current in living beings are electrolytic effects. Living tissues, impregnated with saline solutions, are electrolytes, and the knowledge acquired by the study of electrolytes is directly applicable to them. The electric conductivity of the human body is its electrolytic conductivity. There is need to study the effects of the current on the human body at the surfaces of entry and of exit, and in the depth of the tissues. The electrodes employed for medical applications of electric currents are either insensitive electrodes—carbon, platinum, etc.—or sensitive electrodes—such as zinc, copper, etc.—or electrolytic electrodes formed by aqueous solutions of salts, acids, or bases. In the case of the insensitive electrodes, the anions, after having given up their charge at contact with the anode, become anhydrides, which, in order to make the corresponding acids, carry off hydrogen from the tissues, which they destroy:—$2Cl + H_2O = 2HCl + O$:— and oxygen is liberated. The kations, after contact with the kathode, take the chemical characters of the alkali metals, and carry off the hydroxyl group from the tissues, which they also destroy, freeing hydrogen: $K + H_2O = KOH + H$. If we employ electrodes which can be acted on by the products of electrolysis, the phenomena at the anode consist, firstly, of the formation of acid, with the

destruction of the tissues, and then the attack and dissolution of the electrode by the acids formed. From this there results a salt of the metal of the electrode which gives rise to the phenomena presented by the electrolytic electrodes. When we use as electrodes electrolytes—*i.e.*, solutions of salts, acids, or bases—there is produced by the passing of the current an exchange of ions between the body and the electrodes. At the anode the body gives up its anions and receives the kations of the electrode; at the kathode the body gives up its kations and receives the anions of the electrode.

We can therefore introduce into the body by an electric current kations under the anode and anions under the kathode. All the salts formed of an acid radical or halogen $\bar{R}$, which is electro-negative, and of an electro-positive metal $\overset{+}{M}$, can be represented by the formula $\overset{-m}{R}\ \overset{+u}{M}$. The metal penetrates into the body under the anode, the acid radical under the kathode. The result, therefore, is to change the nature of the salts of the organism. The acid is changed under the kathode and the metal under the anode. If the radical and the metal are the same as those of the organism, which is almost the case when we employ as electrode a solution of chloride of sodium, the effects produced under the electrode are reduced to a minimum. They are not, however, suppressed, for chlorine is not the only electro-negative radical of the organism, and sodium is not the only electro-positive ion, and the exclusive substitution of chloride of sodium for all the salts of the economy has consequences which may result in the death of the tissues. To recapitulate, electrodes formed of saline solutions introduce under the kathode their acid radicals, which act in great measure on the tissues like the corresponding salts of sodium—the iodide, sulphate, phosphate, sulphide, and salicylate of soda. The metal of the salt is introduced under the anode. It acts exactly as its own

chloride would act. We can therefore take for granted the effects produced by the ions of a salt when we know the action on the tissue of the soda salts of its acid and of the chloride of its metal. Let us represent the body by a solution of chloride of soda, and the electrodes by a solution of iodide of potash. In consequence of the passage of the current, all the kations move towards the kathode and the anions towards the anode, and we see that the potassium ions penetrate into the body under the anode, and the iodine ions under the kathode.

	Anode.	Body.	Kathode.	
+	$\overset{+}{K}$ $\overset{+}{K}$	$\overset{+}{Na}$ $\overset{+}{Na}$ $\overset{+}{Na}$ $\overset{+}{Na}$	$\overset{+}{K}$ $\overset{+}{K}$	−
	$\overline{I}$ $\overline{I}$	$\overline{Cl}$ $\overline{Cl}$ $\overline{Cl}$ $\overline{Cl}$	$\overline{I}$ $\overline{I}$	

FIG. 3.—BEFORE THE CURRENT PASSES.

	Anode.	Body.	Kathode.	
+	$\overset{+}{K}$	$\overset{+}{K}$ $\overset{+}{Na}$ $\overset{+}{Na}$ $\overset{+}{Na}$	$\overset{+}{Na}$ K K	−
	I I $\overline{Cl}$	$\overline{Cl}$ $\overline{Cl}$ $\overline{Cl}$ $\overline{I}$	$\overline{I}$	

FIG. 4.—AFTER THE CURRENT PASSES.

All the acid solutions have the same positive ion—hydrogen. They all, therefore, introduce under the anode the ion hydrogen which, with the acid radicals of the economy, will produce the effects of the corresponding acids. If the solutions are sufficiently dilute so as not to act directly on the skin, hydrochloric acid, sulphuric, boracic, acetic acid, etc., will produce identical effects upon the skin. All basic solutions have the same anion—hydroxyl $\overline{OH}$. All introduce, therefore, under the kathode $\overline{OH}$ radicals, which, with the metals of the economy, give

the corresponding bases, and it is the action of these bases which is produced under all the basic kathodes.

The double current, in consequence of which the anions go against the stream towards the anode while the kations descend towards the kathode, is present in the depth of the tissues wherever the electric current passes. In consequence of this there results, at each surface of separation of two different chemical media, a modification in the chemical constitution of these media. Each medium receives the kations of the medium up-stream, and gives it its anions, while it receives the anions of the medium down-stream, and gives up its kations.

All the facts so far ascertained as to the action of electrolytic currents in the body are derived from our knowledge of the effect of an electric current passing through an electrolyte, and the knowledge acquired by the study of electrolytes is directly applicable to them. All the authorities who have studied the absorption of drugs by electrolysis have sought to demonstrate this absorption by finding in the urine traces of the ions absorbed, or by the production of certain physiological effects. The objection has been raised that absorption takes place by the skin without the intervention of the current, and physiologists and physicians continue to deny electrolytic absorption—so much so that in 1900, when I presented my first results to the International Congress of Electro-biology, all the speakers who took part declared that up till then they had regarded the introduction of remedies by the electric current as insignificant or non-existent. My experiences showed, on the contrary, that in conformity with theory the introduction of drugs by electrolysis is regular, and, far from being insignificant, may very easily bring about death. How much more, then, does it permit of our obtaining therapeutic effects? One will readily convince oneself of electrolytic absorption by the following experiment: Apply over the internal surface of the ear of a rabbit a

tampon of absorbent cotton soaked in a solution of sulphate of strychnine. This tampon, covered with a metal plate, and suitably fixed, can be left indefinitely without producing any effect; but if by the aid of a kathode formed of a solution of chloride of soda, and placed on some other region of the body, one makes a sufficiently strong current pass, keeping the tampon soaked in strychnine as the anode, the rabbit is soon seized with typical tetanic convulsions, which become more and more severe till death. This is a test in experimental pharmacology which is easily carried out. The solution of sulphate of strychnine produces no result when it is employed as kathode. If we employ as a kathode a solution of cyanide of potash, we rapidly induce a seizure of tonic convulsions, and the rabbit falls dead. Cyanide of potash at the anode produces no effect. Another equally convincing proof that ions penetrate the body according to the laws of electrolysis is afforded by the employment of coloured ions. If we employ as electrodes on each arm solutions of permanganate of potash, after the passage of the current one will not see any marked change of the skin of the arm by which the current entered where the solution of permanganate of potassium acted as anode; while the point at which the current escaped where the solution of permanganate of potash acted as kathode the skin is starred over with a brown punctate rash, which cannot be removed by washing, as it is situated deeply in the thickness of the skin.

The punctate rash results from the penetration of the permanganate ion, which is immediately reduced by the tissues, and so gives rise to an oxide of manganese. The topography of this punctiform rash shows that the current passes through the skin only by the glands, for the glands alone are thus filled with the ions. The thesis produced in my laboratory by M. Manuel Gonzalez Quijano Sanchez, 'La théorie des ions en électricité médicale,' contains a

photograph of the arm of M. Gonzalez. If, after the penetration of the permanganate ion, we make another experiment, and employ as electrodes solutions of chloride of gold, it is under the anode that the coloured ion—the kation Au (positive)—will penetrate.

Caustic ions also supply us with evidence that ions penetrate according to the laws of electrolysis. Acid solutions will show the cauterization of the glands of the skin under the anode by the penetration of the H ion. Basic solutions show the cauterization of glands under the kathode by the penetration of the OH ion.

The effects of the electric current are specially marked under the electrodes in consequence of their power of changing the ions of the tissues, and these effects are as variable as the number of ions is great. But the current of electricity acts also on the deep tissues, and there again it acts by the ions. It influences the organism by the diffusible ions which it introduces, and also by the exchange of ions which it determines between all the tissues, and between all elements of different chemical composition. We know that the electric current is not propagated except by the double current of ions; wherever the current penetrates into an anatomical element, this element gives up its anions to the liquid which bathes it, and receives its kations. Whenever the current leaves an anatomical element, it gives up its kations to the liquid, which bathes it and receives its anions. To understand this it is enough to recall the representation of the body by a solution of chloride of soda, and of the electrodes by solutions of iodide of potash, and to consider the body—*i.e.*, the solution of chloride of soda—as an anatomical element, while the solution of iodide of potash represents the medium which surrounds this element. We see that by the passage of the current the element changes its kations at the entry of the current, and its anions at the point of escape. The electric current has therefore the power of producing wherever it

passes an exchange of ions between the anatomical elements and the liquids of the body.

All that we have learned regarding ions is applicable to the human body, into which it is very easy to introduce the ions by electrolysis up to toxic doses. We have produced on ourselves toxic effects by the introduction of morphine and strychnine.

The quantity of an ion introduced electrolytically into the human body by a determined quantity of electricity depends on the relative speeds of the ions which participate in the formation of the current, as the following figure shows:

	Anode.	Body.	Kathode.	
+	$\overset{+}{\mathrm{K}}$ $\overset{+}{\mathrm{K}}$	$\overset{+}{\mathrm{Na}}$ $\overset{+}{\mathrm{Na}}$ $\overset{+}{\mathrm{Na}}$	$\overset{+}{\mathrm{K}}$ $\overset{+}{\mathrm{K}}$	−
	$\overset{-}{\mathrm{Br}}$ $\overset{-}{\mathrm{Br}}$	$\overset{-}{\mathrm{Cl}}$ $\overset{-}{\mathrm{Cl}}$ $\overset{-}{\mathrm{Cl}}$	$\overset{-}{\mathrm{Br}}$ $\overset{-}{\mathrm{Br}}$	

FIG. 5.—BEFORE THE CURRENT PASSES.

Anode.	Body.	Kathode.
	$\overset{+}{\mathrm{K}}$ $\overset{+}{\mathrm{K}}$ $\overset{+}{\mathrm{Na}}$	$\overset{+}{\mathrm{Na}}$ Na KK
Br Br Cl	$\overset{=}{\mathrm{Cl}}$ $\overset{=}{\mathrm{Cl}}$ $\overset{=}{\mathrm{Br}}$	$\overset{-}{\mathrm{Br}}$

FIG. 6.—AFTER THE CURRENT PASSES.

The body being represented by a solution of chloride of sodium, and the electrodes by a solution of bromide of potash, if the kation $\overline{\mathrm{K}}$ is displaced with a speed double that of the anion Br, after the passage of the current, at a time when three equivalents have disengaged themselves from each electrode—*i.e.*, for an equal quantity of electricity—one sees that two ions of potassium have penetrated under the anode, while only one ion, Br, has penetrated under the kathode. In general, u being the speed of one

ion, v that of the other, the participation of each in the movement of electricity is $\frac{u}{v+u}$ for the ion whose speed is u, and $\frac{v}{v+u}$ for the ion whose speed is v. The weight of each ion introduced into the body by a quantity of electricity, Q, is given by the formula $\frac{u}{v+u}\,Qe$ for the ion whose speed is u, and $\frac{v}{v+u}\,Qe$ for the ion whose speed is v. In this formula the fraction represents the participation of each ion in the electric current—Q the quantity of electricity employed, a quantity equal to It, the product of the intensity or strength of current by the time—while e represents the electro-chemical equivalent of the substance, an equivalent which is found in special tables. This equivalent is the weight of ions disengaged by a coulomb, and is equal to the chemical equivalent divided by 96,537.

In a succession of papers we have shown that the electric resistance of the human body is the expression of the resistance of the tissues to the movement of ions. At the Congress of the French Association for the Advancement of Science, and at the International Congress of Electro-biology in Paris in 1900, we described a method for the study of the conductivity of the human body consisting in making a circuit with a constant E.M.F., the resistance of the rest of the circuit being negligible relatively to the resistance of the body. If we express the currents thus obtained in ordinates and the time in abscissæ, we obtain a curve which is that of the conductivity of the body at different times of the experiment. This curve varies with the different conditions which influence it, in particular with the nature of the ions introduced. When, for a given potential, the skin is saturated with an ion, the curve of the conductivity is parallel to the axis of the abscissæ. In

these conditions the ordinates of the curves of different ions saturating the skin under the same differences of potential are related to each other as the speeds of the ions in the tissues. A large number of these curves, traced according to our method, which may be used to establish the fractional coefficient necessary for the dosage of ions, may be found in the thesis of M. Gonzalez Quijano.

In our papers in 1900 we showed that the excitability of superficial nerves is profoundly modified in different ways by the different ions.

The diffusion of the different ions in the tissues varies much. While the permanganate ion is not diffused at all, but remains at the point of introduction till it is eliminated, the ion of strychnine, etc., diffuses sufficiently rapidly to produce death in a few minutes. It is not at all certain that the general effects of treatment with ions are the same as those produced by introduction into the stomach or subcutaneously. By these last procedures the ionic medicaments are added; by electrolytic introduction they are substituted for the ions of the organism.

The ion of cocaine introduced by electrolysis produces effects very different from those of a solution of the same drug injected subcutaneously. It produces anæsthesia, but it does not diffusc, and the anæsthesia remains strictly limited to the surface covered by the electrode. It would appear that the ion is introduced by electrolysis, not into the circulation, but into the plasma of the cells.

The initial anæmia is soon replaced by a vasomotor paralysis over the whole surface of introduction. This paralysis disappears gradually, in a few weeks giving place to a pigmented spot which persists for several months, with a marked atrophy of the skin limited to the surface of introduction. If we introduce adrenalin into the skin under a suitable anode, the vascular absorption is indicated by anæmic lines and an ivory whiteness, which marks the track of the efferent veins for a distance of several centi-

metres from the place where the electrode is applied. We can also eliminate some ions from the economy by electrolysis. M. Bordier has demonstrated the electrolytic elimination of the uric ion.

The introduction of electric ions requires as minute precautions as the practice of asepsis. If we make active solutions with merely filtered water, or if we do not make a special choice of the spongy substance constituting the electrode, not only will we fail to get the desired effect, but we will produce an entirely different action. The active solutions should be made with as pure water as possible, recently distilled, or protected from exposure to the air. The spongy bodies ought to be free from all trace of electrolytic substances. The classic chamois - leather covering the metal plates should be absolutely abolished from the equipment of electro-therapy. We must be very careful not to employ materials washed in a lye of carbonate of potash. The materials should be washed in distilled water only, for they should not contain any other electrolytic substance than that which one wishes to employ. Materials of absorbent cotton which satisfy all requirements are easily procurable. When it is possible, the metallic anode should be of the same metal as the electrolytic solution. In all other cases the electrolytic electrode should be sufficiently thick to prevent the introduction of ions produced at the point of contact of the metal of the electrodes.

Our custom is to employ twelve to sixteen thicknesses of a tissue of absorbent cotton. When we wish to circumscribe the surface of introduction exactly, we cut a hole in a sheet of adhesive plaster, which we apply to the skin, and on which we press the electrolytic electrodes. The local action of the ions is the most interesting and important. It is difficult to imagine how ludicrous will appear in the future our present-day method of scattering through the

whole body harmful substances particularly noxious to the most delicate and important tissues, such as the nerve centres, in order to act upon a very limited part of the body which happens to be diseased. It should be one of the aims of medicine to replace general treatment as often as possible by local treatment, and to attain this ideal, the electro-ionic method offers resources which no other method affords. It allows us to introduce into each cell, impermeable to most remedies, a whole series of ions, and to obtain as many different actions as there are ions. When one knows the variety and multiplicity of actions of all sorts which one can produce by saturating the cells of the skin exactly to the degree and depth one wishes with all the electrolytic substances, one is surprised to see medicine remaining content with its applications to the surface—its ointments and pomades, which act only superficially, and of which only an infinitesimal fraction can penetrate into the interior. No doubt certain local remedies are absorbed, and can penetrate in appreciable quantities, but they are more especially those which, from the point of view of local therapeutics, are of little importance—those which pass easily into the general circulation, and which traverse the skin rapidly without modifying it. The skin and the surface of wounds are, with the ordinary means of application, impermeable to powerful alteratives, to strong antiseptics, to coagulators of albumen, agents which electrolysis introduces readily to whatever depth one wishes. The experimental study of the local effects of ions is long and laborious, for not only do the effects vary with each ion, but they vary much with the dose of the same ion. With a moderate dose one obtains an increase of vitality—as, for example, the stimulation of the growth of hair by feeble doses of zinc ions which we called attention to at the Congress of the French Association for the Advancement of Science at Angers in 1903. With a stronger dose there is paralysis of function and death of tissues. For

each ion and for each dose the manifestation of effects is very slow, and requires some weeks and even months of continuous observation. The lesions evolve very slowly, and have a latent period analogous to that of the lesions produced by the X rays.

In a certain number of cases it is easy to interpret the pathogenesis of ionic lesions. It is difficult to produce obvious lesions with the alkaline ions and with the ion of magnesium. The ions of the alkaline earthy metals, on the other hand, readily produce mortification of tissues. The lesions they produce are very characteristic, and are similar for each of the earthy metals. They only differ in their intensity, which increases progressively from calcium to strontium and barium. The introduction of the ions of the alkaline earths is not painful; the animals we experimented upon bore without any sign of discomfort 14 to 15 milliampères of current per square centimetre of electrode. This current was gradually established, and was maintained for thirty minutes. The surface of introduction was then very white, as though the tissues were completely impregnated with carbonate, sulphate, and phosphate of calcium. The following day the surface of introduction had become blackish and ecchymotic. The third day an elastic œdematous swelling had appeared; the fourth day this œdema had increased in thickness; a part of the surface which looked black and ecchymosed was the summit of a truncated cone, 8 to 10 millimetres in height, and the rest of the cone was made up of an elastic œdema. This œdema became hard, and a slough separated at the borders and became detached, leaving a serous ulcer on a hard base resembling a syphilitic chancre. This ulcer deepened, forming a conical crater whose apex penetrated by a tiny orifice into a large cavity, formed by a deep circular separation of the subcutaneous cellular tissue. It was not till after fifteen days from the introduction of the ions that healing began, and, after a month, one had a cicatrix on a very indurated base quite

analogous to the cicatrix of a syphilitic chancre. These lesions, so characteristic and always identical, are certainly the consequence of the introduction into the depths of the tissues of the ions of calcium, and the formation of insoluble salts of calcium with the carbonic, phosphoric, sulphuric, and other ions of the tissues.

All the acid radicals which give insoluble precipitates with the metals of the alkaline earths are caustic in certain doses, but the lesions produced differ according to the ion. One of the most curious effects is produced by the sulphuric ion, which, if introduced by a current of 10 milliampères for forty-five minutes, leaves a dry, parchment-like, glazed surface like varnish. The action is very superficial. The surface becomes black, preserving its polished and shining aspect, and after about three weeks desquamates, leaving beneath it a healthy skin. The ions of the so-called heavy metals are all more or less caustic, probably because of their coagulating action on albumen. One of the most interesting for the physician is the zinc ion. Electricity has been made use of in therapeutics as a coagulating medium in the treatment of aneurisms, angiomas, metrorrhagia, etc., and an anode of platinum has usually been employed for this purpose. It is easy to see experimentally that the coagulating action is a secondary action. With the platinum anode it is due to acids which result from the attack upon the water of the ion radicals discharged at the point of contact with the electrode. Those acids in which hydrochloric acid dominates have little coagulating power, and the decomposition of water has the disadvantage of liberating bubbles of oxygen. The clot around an anode of platinum is frothy and friable. If we practise electrolysis of the serum with platinum needles, we see the frothy perianodal clot broken up by the liberation of oxygen mounting in little lumps to the surface. If we make this experiment with pencils of zinc, not a bubble of gas escapes. The zinc anode envelops itself with a growing cylinder of

coagulated albumen until its weight makes it slip and fall to the bottom of the vessel. The coagulum is so compact that it preserves intact the form of a hollow cylinder. Even in the case of egg-albumen diluted with nine volumes of water, beaten and filtered, which heat makes thick without coagulating into a compact mass, electrolysis with a zinc anode produces a compact and adherent clot. The zinc ion is therefore the better coagulant, and is incomparably superior to the platinum anode.

The physiological properties of organic ions are not less varied.

This brief review of the actions of ions indicates their variety; actions which may be caustic in different degrees—antiseptic, coagulating, producing vascular changes and modifications of sensibility, conductivity, vitality, etc. All these actions are capable of practical application. It is indisputable that the electric current in living tissues, as in all electrolytes, is nothing else than the double current of the ions. The effects of the current are only the effects of the ions. They vary considerably from one ion to the other; the current, or the electro-motive force, is only the force which drives the ions into the tissues.

To expect to appreciate the effects from the obvious electric phenomena, as is so often done, is as little reasonable as to expect to understand all the reactions and all the phenomena of chemistry simply by considering the movements of the hand which pours the reagents into the test-tube. Our studies now published show the need of a change in the way of looking at electro-physiological phenomena. They vastly increase the resources which electricity offers, since, instead of the sole effects of the current, already recognized at the positive pole and the negative pole, they offer effects as varied as the number of the ions, and the different doses in which one can employ them.

V. ELECTROLYTIC TREATMENT

One of the most constant actions of electrolytic treatment is the resolving influence on sclerous and cicatricial formations of a kathodal stream of a solution of chloride of sodium. Joints completely anchylosed rapidly recover their mobility without forced movements or pain. The anchylosis disappears progressively from day to day, and the joints regain all their mobility. It is now more than fifteen years since we first pointed out these effects, and indicated the conditions necessary to obtain them. Since that time our appreciation of the value of this treatment has continued to increase. The resolving action of electrolysis suitably applied is not a matter of chance. It is regular and sure. No other means employed in medicine can be compared with it for efficacy, rapidity, perfection of results, and absence of pain. To apply the treatment, we employ a 1 to 2 per cent. solution of chloride of sodium. The indifferent electrode, the anode, may consist of a local bath for the feet or arms. Frequently we employ a large compress of absorbent cotton-wool folded in sixteen thicknesses impregnated with a warm solution of sodium chloride, which is wrapped round one leg. It is covered with a sheet of tin, which is connected to the positive pole.

The whole is kept in place by a few turns of a bandage. The active electrode, the kathode, is made up in the same way by a bath of salt water, in which the affected region—*e.g.*, the hand—is immersed, or may be by a compress of sixteen thicknesses of absorbent cotton-wool saturated and wrapped round or applied to the affected part—*e.g.*, the knee. It is of advantage to make several turns round the limb, so that there are thirty-two or forty-eight thicknesses of tissue between the skin and the plate of tin connected with the negative pole. This arrangement gives a good surface of contact to the electrolyte, and protects against

the caustic action of the ions produced at the point of contact of the metal plate. The electrodes are then fixed by suitable rheophores to the terminals of the generator, whether this be cells, accumulator, or a reducer of potential in series with a continuous current, a collector, a simple reducer of potential, or a rheostat whose resistance one gradually diminishes. The intensity of the current is gently but progressively increased, as indicated by a milliampèremeter inserted in the circuit. The pain produced is not in proportion to the intensity of the current. It depends rather on the speed with which the intensity is raised. It diminishes or disappears when the strength of current has reached its maximum and remains constant. At first the patient will complain of a current of less than 10 milliampères, but after a quarter of an hour he will tolerate 100 milliampères without any pain. This depends on the fact that at the commencement of the séance the strength of the current rises rapidly and spontaneously owing to the diminution of the resistance. It is therefore very important to increase the intensity of the current very gradually, and to take the patient's sensitiveness into consideration. In these applications the limit of strength of current is only marked by the limit of the patient's tolerance. If the applications are carefully made there is no fear of accidents or burns. With solutions of chloride of sodium burns are only produced if there is any wound of the skin—*e.g.*, some excoriation or pimple which constitutes an orifice, towards which the current rushes and acquires a density which gives the patient a severe burn.

As soon as a patient complains of such localized pain the current should be gradually diminished, the electrode should be removed, and the excoriation should be sought for and wiped with a tampon of absorbent wool soaked in alcohol. It should then be covered with a drop of flexile collodion, which, after drying, does not allow the current to pass, and the séance may be continued. To obtain

rapid results the séances should be prolonged—not less than half an hour in duration with the maximum current. Applications should not be more than three weekly, as the skin and the tissues remain affected for a very long time by each application. The resistance to the destructive action of the current and the tolerance diminish from one séance to the other. If the treatment is prolonged, it is necessary to increase the interval between the séances, giving at first two and then one per week. Success is only certain if the morbid agent has ceased to act and no infectious agent intervenes to counteract the effect of treatment. The rapidity of the result and the degree of efficacy depend essentially on the site of the sclerosis. If the fibrous tissue is immediately under the skin, as in the hands or feet, it is easily accessible to the current, whose action is then rapid and complete. On the other hand, in the hip-joint and the shoulder the sclerosed tissues are surrounded by masses of muscle which are very good conductors, and form a screen which deflects the current and allows only a small part of it to penetrate to the diseased tissues. In these regions the results are slow and incomplete. Progress is always most rapid at the beginning of treatment, because superficial tissues are the first to be strongly influenced, while the action on deep structures is more feeble and slow.

We have often made use of this sclerolytic property of the electric current, and we can foretell its results beforehand. Among the cases treated we may instance a complete anchylosis of the fingers, following an abscess of the hand, in a young soldier who was treated in a military hospital for six months by different methods, among which was forcible movement under chloroform. As there was no improvement, he was dismissed the army. After two electrolytic séances with his hand in a bath of a solution of chloride of sodium, which took the place of the kathode, for a period of thirty minutes with a current of 30 milliam-

pères, he recovered the power of movement so completely that no trace of anchylosis remained. A State forester, after six months of immobilization for a phlegmonous arthritis, had his knee completely anchylosed for five months. After two months' treatment, consisting of nine electrolytic séances, each of which lasted forty minutes, with a kathodic compress impregnated with sodium chloride and a current of 100 milliampères, he could walk perfectly. He was able to resume his duties, which he has continued without interruption ever since. The treatment began with two séances per week, which were subsequently diminished to one séance per week, and then one every fortnight. A young woman had an anchylosed knee-joint after typhoid fever. It was a very painful variety of chronic arthritis, which had remained unaltered for eighteen months. After twelve electric séances, with a kathode applied to the knee, the pain disappeared, as well as all thickening of the tissues, and the movements became free.

The indications for sclerolytic treatment are frequent, and we have had many cases, in all of which the results have agreed with the instances quoted. This electrical sclerolytic treatment is applicable not only to the limbs, but to all parts of the body accessible to the current. It has given us very remarkable results in the treatment of rheumatic scleritis and peri-scleritis. We have cured a number of old cases which had been treated without success by salicylates and iodide of potash in various ophthalmological clinics. The anode is applied to any suitable part of the body, and a tampon electrode covered with several thicknesses of absorbent lint impregnated with a warm solution of sodium chloride is applied and kept for a quarter of an hour on the upper eyelid. The eye being shut, the strength of the current is gradually raised to 5 or 6 milliampères, and two or three séances are given weekly. The pain rapidly subsides, the granulations and the vascularization of the sclerotic disappear, and complete recovery

rapidly ensues. We have had no failures, and we have treated very old cases which had travelled round the ophthalmic cliniques of France and other countries for some years. This treatment gives good results also in cases of chronic iritis with adhesions.

Electric sclerolysis gives results superior to any other method of treatment in affections of the pleuræ, such as painful pleurisies and dry pleurisies with friction, and especially in cases of pleural adhesion. Pleural adhesion appears to us to be a much more important affection than is generally admitted. Scoliosis, which is often regarded as an independent affection, appears to us to be a consequence or a symptom of pleural adhesion. The generally accepted theories as to scoliosis are not very satisfactory, and can only be accepted with difficulty. The osseous theory requires us to accept the existence of an osseous malady which affects only one half of each vertebra. The muscular theory presupposes the feebleness of masses of muscle along the convex side of the vertebral column, and leads one to electrify these muscles. But electrical examinations do not reveal any alteration in the muscles, which are theoretically regarded as being weak. If we abandon these theoretical views, which at the moment play such a rôle in medicine, and if we analyse the facts one by one, we always find in scoliosis that there is a marked atrophy of the thorax on the concave side. The circumference of the concave half of the thorax, measured from the xiphoid cartilage to the spinous processes, is always less than the circumference of the convex half. This difference may be as much as 8 centimetres. The respiratory movements of the concave side are always of less amplitude than those of the convex side, and the muscular masses on the concave side are seen to be somewhat atrophied, so that they appear to have more need of being electrified than those of the convex side. Radioscopic examination always shows a distinct shadow on the concave side, generally at the base,

which is an indication of some pleural thickening, and a deficiency or diminution of all respiratory movements both of the chest wall and the diaphragm. An inquiry into the previous history of the patient elicits the fact that in childhood or infancy the patient had pleurisy or some bronchopulmonary affection of long duration, with a persistent cough. This collocation of evidence leads to the opinion that in infancy or childhood the concave side of the chest has been more or less seriously diseased. In consequence of this disease there has been a retardation of growth and an atrophy of the affected side, which only shows itself at a later date, slowly progressing as the healthy side continues to develop. This atrophy leads to scoliosis, the chief cause of which is pleural adhesion, which by the deficient oxidation, due to restriction of respiratory movements, produces the poor general health which characterizes such patients.

No doubt, in exceptional cases, pleurisy has already been regarded as a cause of scoliosis, but the opinion has been that it was caused by contraction of cicatricial tissue. We doubt this rôle attributed to pleurisy, for if it were real, scoliosis would be met with in adults who had had pleurisy after their growth was completed, and we do not see this. The rôle we attribute to thoracic affections is quite a different one—namely, an arrest of growth, relative to the sound side, and, as a consequence, an atrophy of the whole diseased side.

This etiology and pathogenesis of scoliosis finds a striking confirmation in the remarkable observations on atrophy of the skeleton in scoliotics published by Dr. Desfosses in *La Presse Médicale* on March 12, 1906. He points out that, while the skeleton on the convex side is normally developed, all the bones on the concave side are atrophied, and sometimes this atrophy is considerable. The diseased side is therefore the concave side, and not the convex side, as the muscular theory asserts. Treatment of the cause,

which is the only effective treatment for this condition, is electrolytic sclerolysis. The pleura is separated from the skin only by a relatively thin layer of poorly conducting tissues, and is quite accessible to electric currents.

To apply the treatment we employ a foot-bath of salt water for the anode. The affected side of the thorax is enveloped by a large compress of absorbent lint in sixteen folds, impregnated with hot salt water, and covered by a large sheet of tin connected with the negative pole. The current is gradually switched on, and its intensity is slowly increased to about 100 milliampères. The séance lasts about an hour. For the first month there should be two séances a week, then one weekly séance for two months, and subsequently one every fortnight. The respiratory movements increase in amplitude, the radioscopic shadow lessens, the general state improves, and if the treatment is begun soon enough scoliosis is prevented, as is also the need of wearing orthopædic corsets, which are instruments of torture.

In the treatment of painful pleurisies and intercostal neuralgia, we replace the salt water by a 2 per cent. solution of salicylate of soda. In this way we have introduced the salicylic ion. The pain disappears immediately after the first sitting, and the result is highly appreciated by the patients. We have introduced the iodine ion as a sclerolytic agent in place of the chlorine ion, especially in dealing with anchylosis following septic arthritis. The results have been equally satisfactory, but the iodine ion is much more caustic than the chlorine ion. The intensity of the current should therefore be less, and the séances shorter and at longer intervals. The iodine ion produces a dry cauterization, with cornification and brown pigmentation of the glands by which it is introduced. If a first séance of a certain intensity and duration does not produce an accident, one should not conclude that an equally favourable result will follow the next séance, for the iodine ion produces a

modification of the tissues which lasts a very long time, and notably diminishes their resistance to cauterization by subsequent séances. Many other ions besides the chlorine ion appear to exercise this sclerolytic action—in particular, the OH ion introduced into the tissues round a metallic kathode. In this way, if one introduces a current by an indifferent anode, placed upon the abdomen, and attaches a Béniqué's bougie to the negative pole, so as to make it the kathode, and gives séances twice weekly for ten to fifteen minutes with a current of 5 to 10 milliampères, one will cure the most rebellious urethral strictures. Hard cicatrices become soft; they undergo sclerolysis. There is no need to coat the metallic bougie with an insulating varnish. The current concentrates itself specially on the points of greatest pressure where the resistance is least—*i.e.*, the contracted parts. Electrolysis by a metal uterine sound for the kathode is also the best treatment for stenosis of the cervical canal in dysmenorrhœa. In such cases the current may be raised to 60 milliampères. The same treatment is also applicable to all contractions of the tubes in the body — *e.g.*, the œsophagus, the nasal canal, the Eustachian tube, etc.

We have already pointed out the coagulating effects of the zinc ion. In all hæmostatic or coagulating applications of electricity an anode of zinc should be substituted for the anode of platinum, since experience shows the zinc ion to be the best coagulating agent known to medicine. Metrorrhagia in particular always yields rapidly to electrolysis with a zinc anode and a current of 60 to 100 milliampères for twenty to thirty minutes. Solutions of the salts of zinc are excellent disinfectants, but, like most antiseptics, the solutions act only on the surface. In consequence of their coagulating action on albuminoids, the salts of zinc are absolutely unabsorbed.

The electric current, however, allows one to introduce

into the tissues to any desired depth the zinc ion, which, under the influence of difference of potential, finds its way as easily through coagulated as through liquid albumen. We cannot insist too strongly upon the power which electrolysis alone gives us of making all electrolytic substances, disinfectants, caustics, etc., penetrate into infected tissues to any depth desired. It is strange that medicine has not made more use of such a valuable power. As it is, medical instruction affords us some remarkable contradictions. It proclaims the necessity of asepsis and the utility of antisepsis; it says one should never make a wound in an infected area, and then immediately afterwards it tells us to apply the sharp curette to scrape a tubercular abscess, an infective metritis, or an inflamed naso-pharynx. In these infected fields one opens up innumerable vessels, and hence the risk of introducing germs into the general circulation, and provoking the development of numerous metastatic foci. The student, who sees patients leave hospital after operations of this kind which have had a successful issue, carries into his practice the opinion that these means are absolutely efficacious. He requires years of experience to learn how precarious these results are, and how dangerous are the methods employed.

The electrolytic introduction of ions, and of the zinc ion in particular, carefully performed, not only does not open any vessel nor occasion the least inoculation, but it closes all the vessels and disinfects all the tissues to the depth which one desires to reach. The depth reached is only a question of time. There is no danger in this method, since the zinc ion is not diffused at all.

The treatment of endometritis by a uterine sound of zinc for the anode and a current of 60 milliampères for twenty to thirty minutes once weekly is very efficient in all cases where there is no accompanying affection of the adnexa. The only important point is to watch that the application is not confined to a localized spot, but is over the whole

surface of the affected area. It is a question of technique, of good contact. An injection of 1 per cent. of chloride of zinc, when its employment is possible, will ensure the most uniform contact. In other cases one must proceed by making successive contacts. We have successfully treated, by the electrolytic introduction of the zinc ion, a large number of chronic ulcers, abscesses, and fistulæ—in particular tubercular abscesses and anal fistulæ. In these cases, to ensure good contact, it is of advantage to surround the zinc pencil, which should be introduced into the abscess, with a tampon of absorbent lint soaked in a solution of a zinc salt. The strength of the current depends on the extent of the area treated. It should be as strong as the patient can bear. The séances should be long—at least an hour—if we wish to obtain a rapid result. It is necessary to get either a long séance or several sittings very close together until one believes that he has reached or passed beyond the whole region affected, and one should wait several weeks to see the result before beginning treatment again.

A silver anode, as Drs. Boisseau du Rocher and Zimmern have pointed out, constitutes an excellent agent for local antisepsis, which is very useful in the treatment of endometritis, and especially of chronic urethritis. For this purpose one may use an olivary silver bougie.

At the Congress of the French Association for the Advancement of Science (Angers, 1903) we pointed out the effect of the zinc ion on epithelioma of the face; and Dr. Lewis Jones, of London, published in the *Lancet* of 1905, and in *Les Archives d'Électricité Médicale*, a very interesting study on this subject, and on the employment of the ions in therapeutics.

The introduction of the salicylic ion has given us very remarkable results in the treatment of neuralgias, and especially in tic-douloureux of the face. We have pub-

lished several observations on this subject in *Les Archives d'Électricité Médicale.*

To carry out the treatment of tic-douloureux by the introduction of the salicylic ion, the whole surface of the painful area should be covered. The whole half of the face, and of the head in the case of trigeminal neuralgia, should be covered with a compress of absorbent lint folded in sixteen thicknesses and soaked in a 2 per cent. solution of sodium salicylate. Over this is laid a sheet of tin in connexion with the negative pole of the generator, and the whole is fixed with a bandage. The anode is applied to any part of the body, and a current of 20 to 40 milliampères, according to the sensitiveness of the patient, is very gradually and regularly switched on. The maximum current is allowed to pass for from thirty to sixty minutes. The cessation of the current should be gradual and very gentle, to avoid vertigo. Three séances may be given in a week, as the tissues tolerate the salicylic ion very well. If the neuralgia does not depend on some deep-seated lesion—*e.g.*, bony caries—a recovery rapidly ensues. We have seen an incessant tic-douloureux, which had lasted for thirty-five years and seriously interfered with eating and sleep, disappear in three séances. There has been no return of pain for two years. After recovery the patient, who was very cachectic, put on flesh and regained a robust appearance. In another case we cured an intractable neuralgia which had lasted for four years, and for which the patient had successively undergone without benefit the removal of all the teeth on the affected side, the division of the nerve —which gave only fifteen days' relief—and the resection of the maxillary border of the lower jaw. After her cure by electrolysis the patient's general condition improved, as in the preceding case. We have treated many different cases of neuralgia by this method, which we consider the most efficient at our disposal.

Professor Bergonié, his pupils, and the writer, have intro-

duced with success the salicylic ion in the treatment of chronic rheumatism and rheumatic pains.

Painful or infective cystitis may be treated by electrolytic solutions injected into the bladder. By means of a metal sound covered with rubber an electrolytic current may be conducted into the bladder, and zinc, silver, salicylic, and other ions may be carried into the depths of the vesical mucosa. The same method is applicable to the rectum and all other accessible mucous surfaces.

We have cured several cases of very old ozæna by introducing the zinc ion by means of a nasal anode formed of a pencil of zinc surrounded by a tampon of absorbent lint soaked in a weak solution of chloride of zinc.

Edison, Labattut, Jourdanet, and Porte have successfully treated gout by introducing the lithium ion.

VI. ELECTROLYTIC TREATMENT OF CEREBRAL AFFECTIONS AND NEURASTHENIA

The action of electrolysis on deep tissues has been little studied, and consequently has not been much used. We have seen that it brings about the exchange of ions between all the different tissues of the organism. We have investigated its action on the brain. Two contradictory opinions have stood in the way of the application of electricity to cerebral diseases: the first, that the brain, being enclosed in thecranial box, is not, or at most is only slightly, accessible to electrical currents; the second, that electric currents in the neighbourhood of the brain are very dangerous.* As a matter of fact, the brain is, of all the deep organs, the one most accessible to electric currents, the bones of the skull being quite adequate conductors for conveying the

* Stéphane Leduc, 'De la galvanisation cérébrale,' *Arch. d'Électricité Médicale.*

current, which, besides, with one electrode on the forehead, can hardly go by any other path, for the conductivity of the bones is much less than that of the cerebral substance in which the current concentrates itself as soon as it reaches it. It is not the interposition of resistant tissue like bone, but the interposition of conducting tissue—such, for example, as the muscles along the vertebral column—which hinders the access of currents to deep organs by carrying off the greater part of the current with which we wish to reach the spinal marrow. We have demonstrated directly by experiment on healthy animals and on man that the brain is quite accessible to the electric stream by suppressing all cerebral functions through the influence of certain currents.* One can produce this inhibition in a moment by pressure on a contact, and the cerebral functions reappear instantly the moment the current is suppressed. We can also produce epileptic seizures at will in healthy animals by applying electrical currents to the brain. It is obvious, therefore, that the brain is quite accessible to electric currents. The danger is vertigo and syncope, but this danger is easily avoided. We do not abstain from using the bistoury because it may cut arteries and wound organs which are necessary for life. As we have shown, vertigo is produced whenever the brain is excited asymmetrically—*i.e.*, whenever a current is applied with different strengths to each of the two halves of the brain. We must altogether avoid any sudden variation in the strength of the current, and apply it quite symmetrically to the cerebral hemispheres. The first condition is

* Stéphane Leduc, 'L'électrisation cérébrale,' *Arch. d'Électricité Médicale*, 15 juillet, 1903. 'Production du sommeil et de l'anesthésie générale et locale par les courants électriques,' *Comptes rendus de l'Académie des Sciences*, 1902; Congrès d'Électrobiologie, Berne, 1902; *Archives d'Électricité Médicale*, 1902. Ledue, Malherbe et Rouxeau, et Leduc et Rouxeau, *Comptes Rendus de la Soc. de biologie*. Miss Robinowitch, 'Le sommeil électrique,' *Thèse de Paris*, 1906.

met by the careful employment of the instruments we have described for this purpose—viz., collectors, reducers of potential, and rheostats. The second is always to give to the current an antero-posterior direction, distributing it as symmetrically as possible, so that the two hemispheres will always be equally influenced. Every transverse or oblique current through the brain sets up an asymmetrical excitation, and consequently produces vertigo. To apply the electrolytic action of the continuous current to the brain, we apply over the forehead the sixteen thicknesses of absorbent lint saturated in the electrolytic solution, and over that the plate of pliable metal, and in this instance it is particularly necessary that the cords be firmly soldered on. The whole is fixed with a bandage round the head. The other electrode, made up in the same way, is placed symmetrically on the nape of the neck or on the back, and the strength of the current is gradually increased.

It is not the current which causes pain or discomfort, but the rapidity of varying its intensity. When the séance begins, uncomfortable sensations may be felt when the current is only 2 milliampères, but they disappear even under a current of 20 to 40 milliampères once the intensity has ceased to vary. Care must be taken that all therapeutic applications of this kind should be made with the patient seated on a chair the back of which can be at once thrown down, so that in case of syncope the patient may be immediately placed in the horizontal position with the legs stretched out. In this way all danger is avoided, and the patient at once recovers.

We have studied the effect of cerebral electrolysis on ourselves and others. After the passage of a current of 10 to 20 milliampères for half an hour, directed from the nape of the neck to the forehead—*i.e.*, with the positive electrode on the back of the neck and the negative on the forehead—one feels a sensation of lightness, the head feels more free, ideation is easier, more rapid, and more clear.

This sense of well-being has already been observed by a certain number of doctors. In the third part of the first volume of the *Zeitschrift für Diaetetische und Physikalische Therapie* of Leyden and Goldscheider, Dr. Althaus, of London, insists on the good effects of cercbral galvanization, and his enthusiasm is such that he affirms that this treatment will retard old age. His method, however, is very defective, for he gives the current a transverse direction.

An old judge, whom we treated by continuous currents for facial paralysis, kept coming for a long time after his recovery to ask for another séance, becausc of the sense of well-being which it afforded him. 'I feel lighter,' he said. 'My ideas are more clear. I can concentrate my attention much better, and I can better resist the somniferous effect of law-suits. I can retain more easily the arguments to compare and weigh them up. In fine, my intelligence is more acute, and work is easier.'

Dr. Lewis Jones, in one of the editions of his excellent book 'Medical Electricity,' tells of having treated a lady for a sclerous deafness with continuous currents. Her hearing was not improved, but she felt so much better for the treatment that she insisted on her husband submitting to it in order to improve his faculties.

From these facts proceeds the utility of this cerebral electrolysis in the treatment of neurasthenia. We have used it in some severe cases with unvarying and somctimes remarkable success. In neurasthenic patients, who are timid and anxious, it is not necessary to employ very strong currents. At the most, 10 to 20 milliampères is enough. The séances should be sufficiently long—about half an hour—and should be repeated two or three times per week. In neurasthenia we have found that the most rapid and best results arc obtained by employing a solution of salicylate of soda for the frontal kathode, which introduces the salicylic ion into the cell-plasma of the painful and

affected part. In this way the improvement of neurasthenics is immediate and very marked.

We have also applied cerebral electrolysis to the treatment of organic affections of the brain—*e.g.*, hemiplegia resulting from cerebral hæmorrhage or embolism—and always with some degree of improvement.

On the face of it, one cannot make dead tissues live again, but one can legitimately hope to favour the repair of diseased structures. The continuous current, applied as we have indicated, is still the most sure means known to medicine for acting on the nutrition of cerebral cells. For organic affections, the patients being much less impressionable and more tolerant than neurasthenics, it is of advantage to gradually increase the intensity, and we have often given two or three séances per week of half an hour's duration with a current of 30 to 40 milliampères.

The patients not only feel the influence we have already described on the ideation, but their power of movement improves, and their muscular strength increases. This improvement is always much more marked when there is added to the treatment suitable electrical stimulation of all the paralysed muscles.

APPENDIX

There is no doubt that treatment with ions is destined to become one of the chief lines along which medicine will progress in the future. Up till now it has been neglected because its efficacy had never been properly demonstrated; but to-day, thanks to the genius and enthusiasm of such men as Professor Leduc in France and Dr. Lewis Jones in England, we are beginning to recognize that we have within our reach a weapon to combat disease which may yet do as much for humanity as the great discoveries of Jenner, Pasteur, and Lister.

When we remember that ionic medication is only in its infancy, and think of the large number of substances whose ions have not yet been employed in the treatment of disease, we see what a vast field lies open for patient research, and it is not too much to hope that somewhere in this *terra ignota* are buried secrets which have long been sought after, such as the cure of cancer, of tuberculosis in its protean forms, and of leprosy.

Treatment with ions is within the reach of every practitioner who cares to use it. No expensive apparatus is required. A good portable battery, with twelve to twenty-four cells, with a potential of 18 to 36 volts, an efficient rheostat for the regulation of the current, cords and electrodes, with a milliampèremeter, are all that is necessary, and can be procured by the outlay of a few pounds. In houses equipped with an electric supply from the public mains, accumulators and a suitable switch-board with all accessories can be installed without much expense.

Given a suitable source of electric current, the rest is a matter of observing carefully a few general rules. A point to remember always is that the ions of metals and alkaloids are carried into the body by the current from the positive

electrode, while the ions of the non-metals move in the opposite direction, and must, therefore, be introduced under the negative electrode.

The advantages of the ionic method are: (1) It is easily employed; (2) it is inexpensive; (3) it is comparatively painless, and, except when very strong currents are used, does not require the use of an anæsthetic; (4) so far as is known, there are no remote ill-effects, such as slowly healing 'burns,' which occasionally bring discredit on X-ray treatment; (5) it places in the hands of the physician a useful remedy for dealing with commencing rodent ulcer when the patient refuses to be persuaded of the seriousness of the small sore on the face, and absolutely declines all cutting operations; (6) as improvement usually commences shortly after the ions are introduced, one can soon tell whether the treatment is likely to do good, and, consequently, there is not much time lost waiting for results.

In dealing with a condition such as rodent ulcer, if there is not some obvious improvement after the second séance, it is well to try some other method. In his monograph Leduc lays down the general principles, and in some instances specifies the precise details for employing various ions in the treatment of different diseases. I propose to add a few short notes on some of the technical applications of the system, not dealt with in the body of the monograph, which have been found useful in dealing with various pathological conditions. As it is likely to prove useful not only in ionic treatment, but also in surgery, I begin with a description of—

The Kataphoretic Induction of Local Anæsthesia.

Local anæsthesia may be induced before the introduction of, *e.g.*, zinc ions in sensitive patients, or before other minor surgical operations. The following method has been employed by Quigley with much success before even such extensive operations as removal of tumours of the breast:

A piece of gauze is folded in four thicknesses and cut to the shape of the part to be anæsthetized. The gauze is soaked in a solution of—

℞	Cocaine hydrochlor.	ʒiss.
	Sol. adrenalin (1 in 1,000)	ʒii.
	Aq. steril.	ad ℥ii.

The gauze is covered with metal foil attached to a cord from the positive pole of the battery, and then applied to the area to be treated. The negative electrode, soaked in salt solution, is bound on to any suitable part of the body. Care must be taken that the skin between the positive and negative electrode is dry, to lessen the risk of the current flowing between them along the surface of the skin instead of passing through it into the subjacent structures. The current from a battery of twenty to thirty cells, according to the patient's capacity for bearing the sensation, should be allowed to pass for twenty minutes or half an hour. From time to time the gauze should be dipped again into the cocaine solution, or, keeping the gauze still in position, and with the current still flowing, more of the solution may be injected into the gauze from a pipette or small syringe. As a rule, the anæsthesia induced is absolute, and the admixture of adrenalin renders the subsequent operation almost bloodless, and the anæsthesia more prolonged.

No toxic effects have been observed. The method is particularly useful for operations on surface tumours, such as epithelioma of the lip. It may also be used to anæsthetize the rectal mucous membrane before an operation for hæmorrhoids, by introducing a rectal electrode covered with gauze soaked in the cocaine solution, and enveloped in a thin layer of gold-beater's skin, which will facilitate the introduction of the elcctrode into the bowel, and not interfere to any extent with the passage of the ions into the mucous membrane.

If the hæmorrhoids are pendulous, or in case of rectal polypi, the pedicle may be grasped gently between the blades of a pair of artery forceps which have been covered with gauze soaked in the cocaine solution. The cord from the positive terminal is then attached to the handle of the artery forceps, which is thus converted into the positive electrode. The negative electrode is applied to the abdominal wall, and after the current has passed for some minutes, the hæmorrhoid or polypus may be snipped off or ligatured without the patient feeling any pain.

The Treatment of Rodent Ulcer with Zinc Ions.

In the treatment of rodent ulcer by electric kataphoresis the zinc ions have been found to give the best results.

Before beginning ionic treatment, any scabs or crusts

should be removed from the surface of the ulcer by means of starch and boric poultices. Immediately before the application of the electrodes the ulcer and the adjacent skin should be gently wiped with a piece of cotton-wool wrung out of boiled or distilled water. For active electrodes one requires either pieces of zinc wire, a zinc pencil, or a small sheet of zinc, all of which should be chemically pure.

Before use, the active electrode should be enveloped in lint saturated with a 2 per cent. solution of chloride of zinc. If the ulcer is not very large, the electrode applied over it may be cut to fit it accurately. If, however, the sore is of considerable dimensions, the ions may be introduced by successive applications all over the surface. The active electrode should be attached to the positive pole of the battery, since zinc ions travel from the positive pole towards the negative; and the negative pole should be connected with the indifferent electrode, which should consist of a metallic plate swathed in several thicknesses of lint that has been boiled, and is thoroughly saturated with salt solution. The indifferent electrode should be applied over the nape of the neck, or on some accessible part of the body. Within limits, the larger the indifferent electrode the greater the patient's comfort. The current should be switched on very gradually, commencing at zero, and at the end of the séance the current should be cut off equally slowly, for any sudden interruption gives the patient a most unpleasant shock. This is a most important point which must never be lost sight of in treating patients by kataphoresis.

The current usually recommended is 2 to 3 milliampères for each square centimetre of surface for a quarter of an hour. During the passage of the ions the surface of the ulcer becomes blanched, and when the electrode is removed the diseased surface is seen to be pearly white. A reaction, whose severity varies, ensues, and for some days after the séance the part treated is sore. It may be soothed by some simple lotion or ointment, or by starch and boric poultices.

In cases which are going to do well, healing commences as the reaction subsides, and in ten to fourteen days the ulcer, if small, may be completely healed. If the ulcer is large, healing may occur over part of its area, while the

rest remains unaltered. In such cases a repetition of the treatment will often bring about a rapid cure. A second application should not be made for at least fourteen days after the preceding one. Before each subsequent use of the electrodes their surface should be cleaned with fine emery-paper.

If the patient is nervous and complains of much pain, the ulcer may be anæsthetized by carrying in cocaine solutions with the electric current before beginning treatment.

In the last two or three years many cases of rodent ulcer treated in this way have been completely cured, even after excision, the X rays, and radium had proved unavailing to arrest the progress of the disease.

Other Applications of Zinc Ions.

Chronic Pharyngitis.

Dr. David Arthur* recommends treatment with zinc ions for removing the granulations found in chronic pharyngitis, and considers the results better than those given by the electric cautery.

Ozœna.†

The zinc ions have been found to take away the offensive odour, and materially improve the condition of the diseased mucous membrane.

Hypertrophic Rhinitis.

The coagulating effects of the zinc ions are well seen in the treatment of hypertrophic rhinitis. The erectile tissue over the inferior turbinate bone can be reduced to normal dimensions by zinc electrolysis.

Treatment of Large Inoperable Malignant Tumours.

In America, of recent years, much good work has been done by a method of simultaneous ionization with zinc and mercury, first originated by Massey, of Philadelphia. As very strong currents are employed, the patient must be

* *Medical Electrology and Radiology*, August, 1906, p. 180.
† *Ibid.*

thoroughly anæsthetized with a general anæsthetic. The indifferent electrode may be a large pad of clay mixed with warm water and applied to the patient's back, and over this should be laid a sheet of lead connected with the negative pole. The positive pole is connected with several amalgamated zinc-mercury pencils, which are thrust into the tumour, and the current is progressively increased till the milliampèremeter registers a total current of 800 or 900 milliampères. The current is allowed to pass for a long time—in at least one reported successful case a current of 1,600 milliampères was allowed to pass for three hours—and the ions driven all through the tumour gradually devitalize it, and convert it into an odourless mass, which gradually sloughs out. There is said to be no pain after the operation.

The Ionic Treatment of Multiple Warts.

The resolving action of magnesium sulphate on warts has long been a matter of tradition, and that the old idea had more than a grain of truth in it is shown by the remarkable effects that have recently been found to follow the introduction of magnesium ions over areas covered by multiple warts. The method recommended by Dr. Lewis Jones is as follows: A thick pad of lint thoroughly soaked in a solution of magnesium sulphate whose strength is 20 grains to the ounce is applied over the warty area, and covered with a metal plate connected with the positive pole, and an electrode connected with the negative pole of the generator is applied to any suitable part of the body within reach, and the current is gradually switched on. Its strength is increased to from 5 to 8 milliampères, and the duration of the séance should be fifteen minutes if the patient can tolerate it. If need be, a second application may be made a week later. As a rule, the warts shrivel quickly, and in about a fortnight have completely disappeared.

The Treatment of Hæmorrhoids by Ions.

Instead of the old-fashioned method of injecting pure carbolic acid into an indurated pile, good results may be obtained by inserting a platinum needle connected with

the negative pole into the hæmorrhoidal mass, the positive electrode being applied to the external surface of the body. The current is allowed to pass till the hæmorrhoid becomes blanched. In due time the hæmorrhoid shrivels up. The condition of the rectal mucous membrane may be much improved, according to Patterson,* if, every other day, a copper electrode connected with the positive terminal is introduced into the rectum, and a current of 10 to 15 milliampères is allowed to pass for several minutes.

He has devised a special hollow rectal electrode, the cavity of which may be packed with cotton-wool soaked in a solution of copper sulphate for the more efficient accomplishment of this object.

Boils and Carbuncles.

For the rapid resolution of furuncles, the following method has been recommended: An epilation needle connected with the negative pole of the electric supply is introduced into the orifice of the affected follicle, and a current of 10 milliampères, if the patient can tolerate it, or less if the pain is very severe, is allowed to pass for several minutes. The needle is gently rotated and moved about so as to reach all parts of the infected follicle.

The hydrogen evolved forces out all necrotic matter through the orifice. The needle is then removed, and a clean needle connected with the positive pole is introduced. The oxygen generated round the positive needle disinfects the follicle and completes the cure. All follicles in the neighbourhood of a boil which show any signs of inflammation should be treated in this way, which affords a means of effectively destroying the bacteria *in situ*. Marcus,† who first described this method, claims for it a degree of efficiency that no other method attains.

'Interstitial Electrolysis.'

More than a decade ago Gautier did much good work by a method which he called 'interstitial electrolysis,' but which was, after all, only an early application of ionic therapeutics.

* *Journal of Advanced Therapeutics*, March, 1907.

† *Münchener Medicinische Wochenschrift*, May, 1905.

He used copper needle-shaped electrodes connected with the anode, and thrust into the diseased tissues. He employed the method in the treatment of acne, sycosis, lupus, tubercular abscesses, etc., and he increased its efficacy by injecting into the tissues to be treated a small quantity of a solution consisting of—

Potassium iodide	1 part.
Glycerine	3 parts.
Water	20 parts.

Unfortunately, his experiments have not received—in this country, at least—the attention they deserve. The method was particularly useful in the treatment of obstinate sycosis.

Neuralgia.

While this book was in the press I have had a remarkable proof of the efficacy of the salicylic ion in the treatment of neuralgia following herpes. The patient had not slept for four nights because of the intense pain, but found relief after the ions from a 2 per cent. solution of salicylate of soda had been carried into the affected zone by a current of 7 to 10 milliampères for thirty minutes. She was able to sleep immediately afterwards, and when next seen had had no return of the pain.

Ringworm and Lupus Erythematosus.

There are evidences that the copper ions produce great improvement in these two conditions.

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THE END

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